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ABSTRACT

Human engineering guidelines for the design of instructor/operator stations (IOSs) for aircrew training devices are provided in this handbook. These guidelines specify the preferred configuration of IOS equipment across the range of the anticipated user sizes and performance capabilities. The guidelines are consolidated from various human engineering design standards, scientific literature surveys, and empirical human factors investigations. They address five major topics typically encountered in human engineering IOS design efforts. These are: (1) electronic displays; (2) manual controls; (3) control placement; (4) workstation design; and (5) workstation seating. For each of the design guidelines presented, the sources from which the guideline was extracted, the source dates of publication, and the corresponding source design specifications are provided. Anthropometric data are also included in this handbook to identify the human body dimensions and arm reach distances of males and females. In addition, an annotated bibliography of published IOS design studies is provided. (Author/TW)

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AIR FORCE HUMAN RESOURCES LABORATORY

INSTRUCTOR/OPERATOR STATION DESIGN HANDBOOK FOR AIRCREW TRAINING DEVICES

Harold D. Warner
University of Dayton Research Institute
300 College Park Avenue
Dayton, Ohio 45469

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85240-6457

October 1987
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The purpose of this handbook is to provide human engineering guidelines for the design of flight simulator instructor/operator stations (IOSs). Guidelines are included for (a) electronic displays, (b) manual controls, (c) control placement, (d) workstation design, and (e) workstation seating. Human engineering design standards, scientific literature surveys, and empirical human factors investigations constituted the primary sources from which the guidelines were established. The specific sources from which each guideline was extracted, the source dates of publication, and the source design specifications are provided for each of the IOS design recommendations in the handbook. The human body dimensions and arm reach distances of representative groups of both male and female operators are also included in the handbook. Finally, an appendix is provided containing a comprehensive listing of published IOS design investigations.

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SUMMARY

Human engineering guidelines for the design of instructor/operator stations (IOSs) for aircrew training devices are provided in this handbook. These guidelines specify the preferred configuration of IOS equipment across the range of the anticipated user sizes and performance capabilities. The guidelines are consolidated from various human engineering design standards, scientific literature surveys, and empirical human factors investigations. They address five major topics typically encountered in human engineering IOS design efforts: (a) electronic displays, (b) manual controls, (c) control placement, (d) workstation design, and (e) workstation seating. For each of the design guidelines presented, the sources from which the guideline was extracted, the source dates of publication, and the corresponding source design specifications are provided. Anthropometric data are also included in this handbook to identify the human body dimensions and arm reach distances of males and females. In addition, an annotated bibliography of published IOS design studies is provided.

PREFACE

This handbook establishes human engineering guidelines for the design of instructor/operator stations for aircrew training devices. The work was concluded under the current University of Dayton Research Institute flying training research support contract, No. F33615-84-C-0066, sponsored by the Air Force Human Resources Laboratory, Operations Training Division (AFHRL/OT). Development of the handbook was initiated at the request of Mr. H. Craig McLean, Air Force Systems Command, Aeronautical Systems Division (ASD/YWE).

A special word of thanks is due to Ms. Margaret Keslin for her persistent and patient support in the preparation of this report.

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INSTRUCTOR/OPERATOR STATION DESIGN HANDBOOK FOR AIRCREW TRAINING DEVICES

1. INTRODUCTION

1.1 Objective

This handbook provides human engineering guidelines for the design of instructor/operator stations (IOSs) for aircrew training devices. These guidelines specify the preferred configuration of IOS equipment across the range of the anticipated user sizes and performance capabilities. The guidelines are consolidated from various human engineering design standards, scientific literature surveys, and empirical human factors evaluations. The systematic application of these guidelines can improve the overall operability of the workstation, resulting in reduced workload, errors, and safety hazards.

1.2 Scope

This design handbook is comprised of eight sections and an appendix that address the following:

Section 1 - Introduction
Section 2 - Electronic Displays
Section 3 - Manual Controls
Section 4 - Control Placement
Section 5 - Workstation Design
Section 6 - Workstation Seating
Section 7 - Anthropometric Data
Section 8 - References
Appendix A - Definitions and Units of Measurement
Appendix B - IOS Design Reports

The IOS design guidelines are presented in Sections 2 through 6 in the order they are generally encountered in workstation design projects. The guidelines appearing in these sections were selected on the basis of applicability to IOS design. Human body dimensions and arm reach data are presented in Section 7. The various sources from which the equipment design and anthropometric data were obtained are listed in Section 8. Measurements that are frequently used in the text are defined in Appendix A, and the corresponding computational procedures are provided. These measures are (a) visual angle, (b) illuminance, (c) luminance, (d) reflectance, (e) required illuminance, and (f) luminance (brightness) contrast. Appendix B provides a partial bibliography of published human factors IOS design studies.

1.3 Guideline Format

The IOS design guidelines in this handbook are presented in the following format whenever practicable:

x.x Title

a. IOS Design Recommendation

Guideline

b. References: Requirements

1. Source (Date): Design specification
.
.
.
x. Source (Date): Design specification

The title identifies the specific area the guideline addresses, and each is numbered to provide rapid user access. The guideline corresponding to the title appears under subheading a. IOS Design Recommendation. The sources from which the guideline was extracted, the publication dates, and the associated design specifications are identified under subheading b. References: Requirements. The original units of measurement (e.g., inches and millilamberts) that were used in the source materials have been preserved in the source design specification.

2. ELECTRONIC DISPLAYS

2.1 Introduction

The IOS visual displays provide the information required to instruct the simulator training exercises. These displays permit the flight instructor to monitor the activities of the trainee, to evaluate the trainee's performance, and to monitor the system state parameters of the simulated aircraft. If the display information is incomplete or if it is difficult to read from the displays, the instructional capability of the IOS will be seriously degraded. In this section on electronic displays, design guidelines are presented to maximize the readability of the displays. The following display types are addressed: (a) cathode-ray tube (CRT) displays, (b) color CRT displays, (c) television (TV) displays, and (d) dot and stroke matrix displays.

2.2 Cathode-Ray Tube (CRT) Displays

2.2.1 General Requirements

2.2.1.1 Viewing Angle

a. IOS Design Recommendation

The preferred viewing angle between the viewer's normal line of sight and the center of the CRT display is 90° (i.e., perpendicular to the normal sight line). The normal line of sight is about 15° below the horizontal sight line. The angle may be reduced to 45° if the situation warrants, but under no circumstances should the angle be less than 30°.

As the viewing angle is reduced, the angular size of the display symbols will decrease and specular reflections (glare) from overhead light fixtures will increase. Figure 2-1 illustrates the recommended viewing angles.

b. References: Requirements

1. AFSC DH 1-3 (1980): The CRT scope face should be in a plane that is perpendicular to the operator's normal line of sight. If oblique viewing conditions are imposed, there will be a loss in visibility of threshold symbols as a function of the reduction of visual angle.

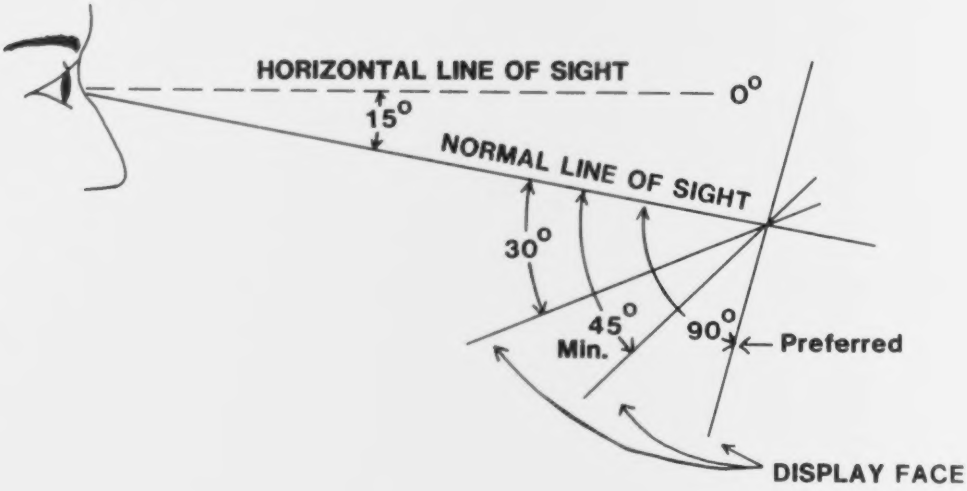


Figure 2-1. Recommended Viewing Angles.

However, the CRT scope may be tilted 30° from the plane that is normal to the line of sight without significantly affecting the detection of weak display symbols.

2. Bassani (1980): The capability of the display to maintain contrast as the viewing angle is increased determines the limits of the acceptable viewing angle. The user of a display should not be required to view it at a horizontal viewing angle of more than 75° from normal (perpendicular to the display surface). The displayed character dimensions should be adjusted to compensate for those dimensions that appear smaller when the displays are to be viewed at large viewing angles.

3. Elke, Malone, Fleger, and Johnson (1980): The optimal horizontal angle for CRT viewing is 90° straight on. The viewer should not be seated at a viewing angle smaller than 45° and should never be required to view a display from an angle less than 30°.

4. IBM Corporation (1979): The viewing angle involves a tradeoff between a reduction in the angular size of the display symbols and glare, or reflections, from the surface of the display. Tilting the display face away from a plane that is normal to the line of sight, which is about 10° below the horizontal, has a very small effect on the angular size of the characters for the first several degrees:

Screen surface orientation in degrees away from a plane normal to the line of sight (degrees)	0	5	10	15	20	25
Reduction of the angular height of the symbol (percent)	0	0.38	1.23	3.41	6.03	9.37

However, for any display tilt, there may be a very significant effect of glare. To reduce glare from overhead light fixtures, the display should be tilted forward. No specular reflections from overhead lights will reach the viewer's eyes if the display screen is located near the vertical and below the eye height.

5. MIL-HDBK-759A (1981): CRT screens should be perpendicular to the operator's normal line of sight at the screen center whenever feasible. No part of any screen, including secondary CRTs, should have a viewing angle of less than 45° from the operator's normal position.

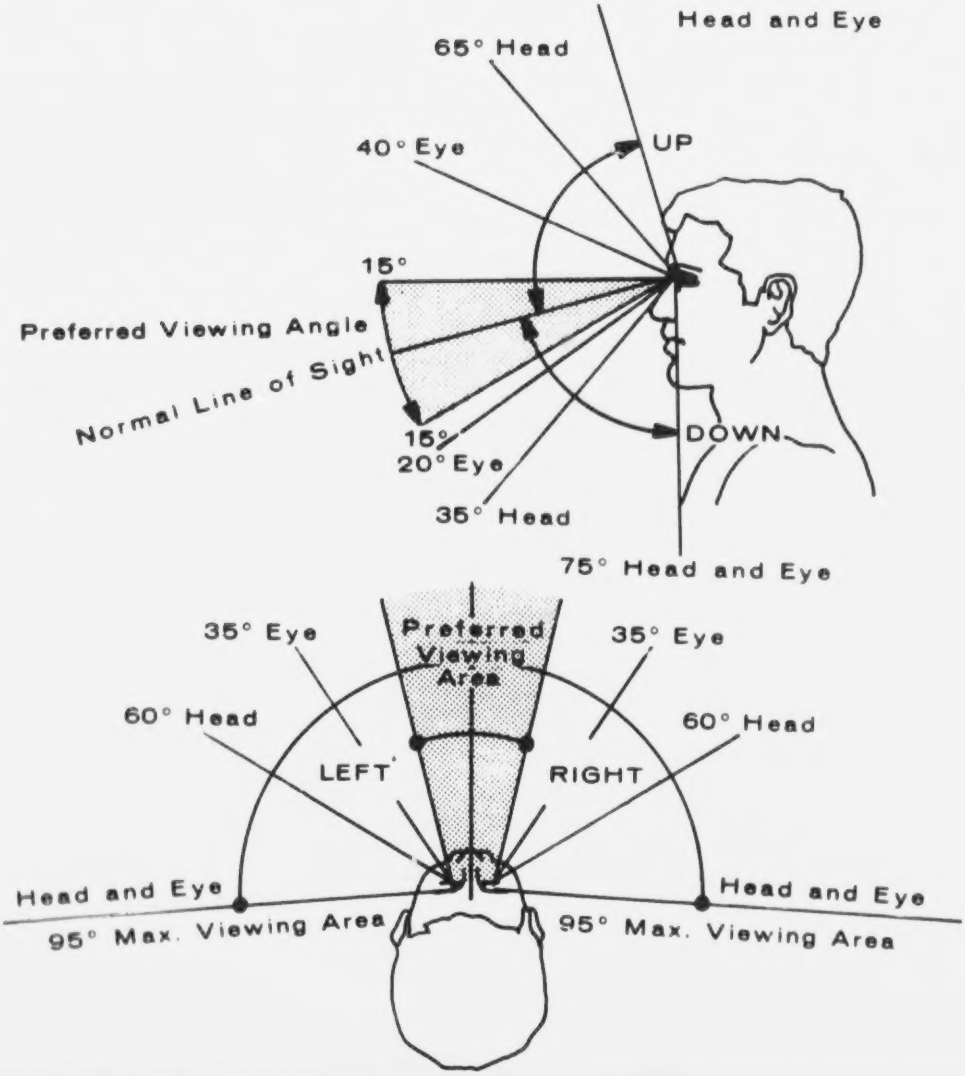
6. MIL-STD-1472C (1981): Display faces shall be perpendicular to the operator's normal line of sight (i.e., 15° below the horizontal line of sight) whenever feasible and shall not be less than 45° from the normal line of sight. Parallax shall be minimized.

7. Woodson (1981): The viewing angle should not be less than 30° from the perpendicular axis.

2.2.1.2 Visual Fields

a. IOS Design Recommendation

In the placement of visual displays, consideration should be given to the preferred viewing area and the operator's eye and head rotational limits. The most frequently used and the most important displays should be located in the preferred viewing area, which is 15° above and below and on either side of the normal line of sight. The preferred viewing area, as well as the eye and head rotational limits, is shown in Figure 2-2.


Head and Eye
65° Head
40° Eye
UP
15°
Preferred Viewing Angle
Normal Line of Sight
15°
20° Eye
35° Head
DOWN
75° Head and Eye
35° Eye
Preferred Viewing Area
35° Eye
60° Head
60° Head
LEFT
RIGHT
Head and Eye
95° Max. Viewing Area
Head and Eye
95° Max. Viewing Area

	PREFERRED*	MAXIMUM*		
		EYE ROTATION ONLY	HEAD ROTATION	HEAD AND EYE ROTATION
UP	15°	40°	65°	90°
DOWN	15°	20°	35°	85°
RIGHT	15°	35°	60°	95°
LEFT	15°	35°	60°	95°

*Display area on the console defined by the angles measured from the normal line of sight.

Figure 2-2. Visual Field. (From MIL-HDBK-759A, 1981.)

b. References: Requirements

1. IBM Corporation (1979): The preferred placement for visual displays is within a 30° cone that has been lowered 10° from the horizontal line of sight. Because display height is a function of eye position, the display should be located such that the normal line of sight falls in the upper half of the display.

2. MIL-HDBK-759A (1981): Displays should be within the observer's head and eye rotational limits, which are illustrated in Figure 2-2.

3. MIL-STD-1472C (1981): The displays most frequently used should be grouped together and placed in the optimum visual zone, and important or critical displays should be located in a privileged position in the optimum projected visual zone. This zone is about 15° above and below, as well as left and right of, the normal line of sight, encompassing an area about 30° both horizontally and vertically.

4. Woodson (1981): For seated operations, the viewer's line of sight should not exceed about 30° vertically or horizontally; that is, about 15° on either side of the operator's normal center-of-the-display viewing angle.

2.2.1.3 Viewing Distance

a. IOS Design Recommendation

The viewing distance from the observer's eyes to the display screen should be between 406.4 and 508 mm (16 to 20 in.) to prevent visual fatigue effects. When the periods of display observation are short or when the display signals are dim, the viewing distance may be reduced to between 254 and 355.6 mm (10 to 14 in.). The maximum viewing distance for a seated operator should be 711.2 mm (28 in.). When the displays are placed at a greater viewing distance, modifications may be required to the display parameters, which include display size, symbol size, symbol brightness, line spacing, and resolution.

b. References: Requirements

1. AFSC DH 1-3 (1980): A viewing distance of 406.4 mm (16 in.) appears to be the minimum for the prevention of visual fatigue and should be used whenever possible. However, shorter viewing distances increase the visual angle subtended by display targets and therefore result in improved visibility. Consequently, if viewing periods are short and display symbols are dim, the viewing distance may be reduced to 254 to 304.8 mm (10 to 12 in.).

2. Booth and Farrell (1979): A viewing distance of 400 mm (16 in.) is a reasonable minimum if a single, fixed viewing distance is required because of design constraints. However, viewing distance and display size should be considered together because of their strong interaction.

3. Elke et al. (1980): A viewing distance of 18 in. shall be provided if possible. The distance may be reduced to 14 in. for short scope observation periods and when display signals are dim. Viewing distances less than 16 in. should be avoided because of eye strain and fatigue effects. The maximum viewing distance for a single seated operator shall be 28 in. unless the screen size and symbol size are increased accordingly.

4. IBM Corporation (1979): The maximum distance between the display screen and the operator's eyes is determined by display character size. The preferred viewing distance of many operators is between 350 and 500 mm.

5. MIL-HDBK-759A (1981): Displays should not be located so far from the operator that the displayed material cannot be read or recognized, nor should the display be located so close that visual accommodation becomes difficult and tiring. The minimum viewing distance should not be less than 330 mm and preferably not less than 405 mm.

6. MIL-STD-1472C (1981): Whenever practicable, a 400 mm (16 in.) viewing distance shall be provided; but the viewing distance may be reduced to 250 mm (10 in.) when viewing periods are short or when display signals are dim. Display design should allow viewing from as close as the observer desires. If the displays must be placed at viewing distances greater than 400 mm, they shall be appropriately modified in aspects such as display size, symbol size, brightness ranges, line-pair spacing, and resolution.

7. Woodson (1981): The optimum viewing distance for typical console operations is 18 to 20 in. (457 to 508 mm) for a 12- to 19-in. (305- to 483-mm) screen. The maximum viewing distance is about 20 ft. (6.0 m), depending on the size of the display.

2.2.1.4 CRT Alphanumeric Character Size

2.2.1.4.1 Character Height

a. IOS Design Recommendation

Character height is typically expressed in terms of the visual angle, in minutes of arc, subtended at the viewer's eye. Because the viewing distance is included in the computation of visual angle, the viewing distance must be defined before the height of the display characters can be determined. CRT alphanumeric character height should be in the range of 12 to 25 minutes of arc. When the visual acuity of the viewers is normal, display character height may be in the range of 12 to 16 minutes of arc. Character height should be increased to between 22 and 25 minutes of arc when the viewer's visual acuity is not expected to be normal. These heights are for numerals and uppercase letters.

b. References: Requirements

1. Bassani (1980): Character height is specified in reference to numerals and uppercase letters. They should subtend 12 minutes of arc at the greatest anticipated viewing distance for people with near-normal vision who use the display in the normal course of their work. The preferred character height under these conditions is determined as follows:

Minimum height = either 0.0035 x viewing
distance (mm) or 2.54 mm
(whichever is larger)

For casual viewers who are not expected to have near-normal vision, the character height should subtend 24 minutes of arc at the greatest anticipated viewing distance. The preferred character height is determined as follows:

Minimum height = either 0.007 x viewing
distance (mm) or 5.08 mm
(whichever is larger)

2. Elke et al. (1980). Alphanumeric characters should subtend at least 12 to 15 minutes of visual angle. The characters should be uppercase letters.

3. Hemingway, Kubala, and Chastain (1979): Symbol height should subtend 22 to 25 minutes of arc for the fastest possible recognition, and visual angles less than 16 minutes of arc should be avoided.

4. IBM Corporation (1979): A minimum character height of 16 minutes of arc is the accepted standard. Simply stated, the height should not be less than 1/200th of the viewing distance, which is about 17 minutes of arc. The requirement for 16 minutes of arc is applicable to uppercase letters. Lowercase letters may be proportionally smaller as warranted for appropriate graphic representation.

5. MIL-HDBK-759A (1981): Alphanumeric characters presented on CRT displays should subtend at least 15 minutes of arc.

6. Shurtleff (1980): Symbol height should be in the range of 10 to 15 minutes of arc for people with normal visual acuity. The recommended size is 15 minutes of arc, to ensure accurate letter identification and to reduce the effects from the anticipated display degradation. As an approximation, symbol height can be determined through the application of the following formula:

$$\tan \theta = \frac{\text{letter height}}{\text{viewing distance}}$$

7. Woodson (1981): Under optimum viewing conditions, alphanumeric characters should subtend at least 12 minutes of arc. When viewing conditions are not good, the characters should be about 25 minutes of arc.

2.2.1.4.2 Character Width

a. IOS Design Recommendation

Alphanumeric character width is typically defined in terms of width-to-height (or height-to-width) ratio rather than absolute size. The recommended width-to-height ratio for display characters is between 1:2 and 1:1; that is, character width between 50% and 100% of character height. A ratio of about 3:4 (75%) should provide adequate recognition speed and accuracy if a single, average ratio is required.

b. References: Requirements

1. Bassani (1980): A height-to-width ratio of between 1:1 and 1:0.7 is acceptable for letters and between 1:0.7 and 1:0.5 for numbers. The height-to-width ratio for characters when displays are used at large horizontal viewing angles (over 60°) should be decreased as follows:

$$\text{Height}/(\text{width} + \text{width} \sin (\text{viewing angle} - 60))$$

2. Elke et al. (1980): The height-to-width ratio for CRT alphanumerics should be between 7:5 and 3:2, and the ratio for characters in an airborne environment should be between 2:1 and 1:1.

3. Hemingway et al. (1979): The optimum width-to-height ratio is a function of the particular symbol, but it should be about 1:2.

4. Shurtleff (1980): A symbol width between 75% and 100% of symbol height is recommended for displays.

5. Woodson (1981): For maximum legibility and fastest recognition, an alphanumeric character width-to-height ratio of 2:3 to 3:5 is best.

2.2.1.4.3 Character Stroke Width

a. IOS Design Recommendation

Alphanumeric character stroke width is typically specified in terms of stroke-width-to-character-height ratio (or character-height-to-stroke-width) rather than absolute width. Generally the stroke width-to-height ratio should be between 1:3 and 1:20. For light characters on a dark background, the smaller widths should be used, preferably 1:10 to 1:20; and for dark characters on a light background, the larger widths should be used, preferably 1:3 to 1:10.

b. References: Requirements

1. Bassani (1980): Character-height-to-stroke-width ratios of between 10:1 and 20:1 are acceptable for light characters on a dark background, and ratios between 5:1 to 15:1 are acceptable for dark characters on a light background.

2. Elke et al. (1980): Stroke-width-to-character-height ratios should be in the range of 1:6 to 1:10. The smaller width should be used for light characters on a dark background. In an airborne environment, alphanumeric stroke width should be 1:5 of the character height.

3. Hemingway et al. (1979): The stroke width should vary between 12:100 and 20:100 of the symbol height, depending on the particular symbol. However, the stroke-width-to-character-height ratio should be between 8:100 and 10:100 for symbols subtending less than 16 minutes of arc.

4. Shurtleff (1980): A stroke-width-to-character-height ratio of 1:4 to 1:8 is recommended for displays.

5. Woodson (1981): Stroke-width-to-character-height ratios between 2:6 and 1:10 are recommended.

2.2.1.4.4 Character Spacing

a. IOS Design Recommendation

The space between characters is the horizontal distance between the edges of adjacent characters. The spacing for light characters on a dark background should be wider than for dark characters on a light background. Character spacing should also be increased when off-axis viewing and non-optimal viewing conditions are anticipated. Under these conditions, a horizontal character spacing between 25% and 63% of the character height should be used. With low ambient illumination (1.0 fL), the lower spacing limit is recommended, but character separation should be twice the height of characters when ambient illumination is between 20 and 40 fL.

b. References: Requirements

1. Bassani (1980): The space between characters should not be less than 0.8 times the character stroke width. A separation that is between 1.0 and 1.3 times the character stroke width is recommended.

2. Elke et al. (1980): The spacing between characters should be wider for light symbols on a dark background than for dark symbols on a light background. In general, the separation should be between 25% and 63% of character height. The lower limit is recommended for low ambient illumination (1.0 fL) conditions and when the visual angle subtended by the characters is under 16 minutes of arc. For illumination levels between 20 and 40 fL, character separation should be twice the height.

3. Hemingway et al. (1979): The space between symbols should be at least 25% of the symbol height.

4. Shurtleff (1980): For direct, in-line viewing, character separation can be as little as 8% to 10% of the height. However, for off-axis viewing of 45° or more, the separation should be increased to 25% to 50% of the height. If nonoptimal display conditions are anticipated, spacing should not be less than 25% of the height.

2.2.1.4.5 Line Spacing

a. IOS Design Recommendation

The space between lines is the distance from the bottom edge of the capital letters on one line to the top edges of the capital letters on the next line below. The spacing should be between 0.4 and 1.0 times the height of the capital letters. The upper limit of the range may be exceeded to meet format requirements.

b. Reference

The design recommendation was adapted from Bassani (1980).

2.2.1.4.6 Characters Per Line

a. IOS Design Recommendation

The maximum number of characters on one line of the CRT display should be between 40 and 80.

b. Reference

The source of this design requirement is Bassani (1980).

2.2.1.4.7 Uppercase and Lowercase Letters

a. IOS Design Recommendation

Uppercase refers to capital letters, and lowercase refers to small letters. Uppercase letters should be used only for indications (e.g., EMERGENCY SHUT OFF, MOTION ON, and POWER ON). In displays that provide narrative, both uppercase and lowercase letters should be used (e.g., "Press CHOCKS OFF to enable aircraft to taxi").

b. Reference

Except for the examples, Bassani (1980) suggested this design approach.

2.2.1.4.8 Character Font

a. IOS Design Recommendation

Character font refers to the shape and style of letters, numbers, and symbols. In general, common fonts should be used; and vertically oriented characters are recommended. The Lincoln/MITRE font (Figure 2-3) seems to be preferred; but the Mackworth, Leroy, and MIL-M-18012 fonts are acceptable.

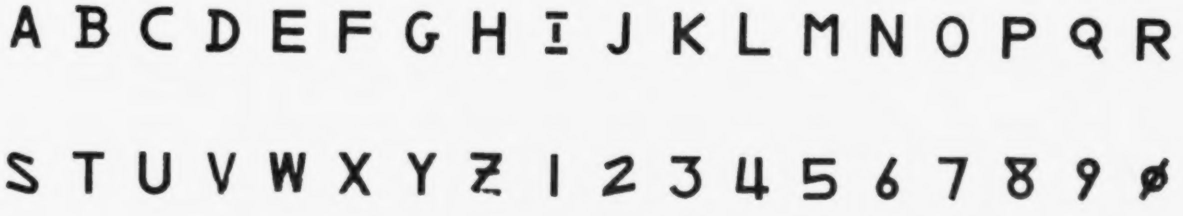

A B C D E F G H I J K L M N O P Q R
S T U V W X Y Z 1 2 3 4 5 6 7 8 9 0

Figure 2-3. Lincoln/MITRE character font. (From Shurtleff, 1980.)

b. References: Requirements

1. Bassani (1980): Helvetica Medium (or equivalent) is recommended as the standard for display use, and Helvetica Bold Condensed (or equivalent) is recommended when display area limitations prevent the use of Helvetica Medium. However, these recommendations are not applicable to CRT or plasma display terminals.

2. Hemingway et al. (1979): Common fonts are preferred. The Mackworth, Lincoln/MITRE, Leroy, and MIL-M-18012 fonts are recommended. Fonts with variable stroke widths and/or serifs should not be used.

3. Shurtleff (1980): The Lincoln/MITRE font is preferred for display applications.

4. Woodson (1981): The closer the character style is to the legibility guidelines for printed matter, the more readable the characters will be. If rapid readout is not a requirement, modified, matrix-type characters are acceptable. Although vertical characters are preferred, sloping (italic) characters are frequently used and are acceptable for single values; that is, when the separation between character lines is at least equal to the character height.

2.2.1.5 CRT Target Symbols

2.2.1.5.1 Target Size

a. IOS Design Recommendation

Under operational viewing conditions, complex geometric and pictorial target symbols should not subtend a visual angle less than 20 minutes of arc.

b. References: Requirements

1. AFSC DH 1-3 (1980): Targets should subtend at least 12 minutes of arc under optimal viewing conditioning, to ensure accurate identification. Under operational conditions, 20 minutes of arc is probably required.

2. Elke et al. (1980): Geometric and pictorial symbols should subtend a visual angle of at least 16 minutes of arc. Critical targets and targets of complex shape that are to be distinguished from complex, nontarget shapes should subtend not less than 20 minutes of arc; and they should have a resolution of at least 16 to 17 lines per symbol height.

3. MIL-HDBK-759A (1981): Complex shapes should subtend a visual angle of at least 20 minutes of arc.

4. MIL-STD-1472C (1981): Complex target shapes that are to be distinguished from nontarget shapes that are also complex should not subtend a visual angle less than 20 minutes of arc, and they should not subtend less than 10 lines or resolution elements.

5. Woodson (1981): The minimum size of target symbols should be about 12 minutes of arc under fairly ideal viewing conditions, and the preferred size is approximately 20 minutes of arc.

2.2.1.5.2 Target Separation

a. IOS Design Recommendation

The minimum separation between targets should be at least 0.1 minute of arc for detection purposes.

b. Reference

The design recommendation is from Woodson (1981).

2.2.1.6 Display Lighting

2.2.1.6.1 Luminance

a. IOS Design Recommendation

Luminance is the amount of light reflected or emitted from a surface. Screen luminance should be adjustable throughout the range from the visual threshold to the threshold of glare and should be compatible with the operating characteristics and life expectancy of the CRT. Under normal lighting conditions, the luminance should be between 10 and 60 fL; in dark areas, it should be in the range of about 0.06 to 2.0 fL.

b. References: Requirements

1. Elke et al. (1980): Screen luminance of at least 25 mL should be used although the preferred luminance is 50 mL. The screen luminance for CRTs used in dark areas should be below 2.2 mL.

2. IBM Corporation (1979): Visual acuity does not improve significantly for average luminances above about 30 cd/m^2 (10 fL).

3. MIL-HDBK-759A (1981): Screen luminance should be compatible with the operating characteristics and life expectancy of the CRT. The CRT should not be driven beyond its normal value in an effort to achieve greater luminance because this could burn the screen or reduce its life. The luminance of the faintest information displayed requiring an operator response should be well above the operator's threshold, taking into consideration target size and presentation rate, clutter, phosphor color, and ambient illumination.

4. Schmidtke (1980): It is a basic ergonomic principle that luminance adjustment must be provided, generally from the threshold of visibility to the threshold of glare. For displays used in both dark and bright rooms, the range of adjustability has to be from about 0.2 cd/m^2 (0.06 fL) to 200 cd/m^2 (60 fL).

5. Shurtleff (1980): Screen luminance should be in the range of 10 to 50 fL. For most applications, it is probably not necessary for the luminance to exceed 20 fL.

6. Woodson (1981): Under normal ambient light levels, a line brightness of 50 fL (± 40) is required. For lower ambient light conditions, the screen brightness should be capable of being adjusted to lower levels.

2.2.1.6.2 Luminance Contrast

a. IOS Design Recommendation

Luminance contrast is the difference between the luminance of the display characters and the luminance of the background. In general, if the contrast is too small, the display characters will blend into their background; and if the contrast is too large, the characters will appear blurred. The recommended luminance contrast percentage is between 88% and 95%. Both high and very low ambient light conditions will restrict the contrast range. In addition, absolute luminance and character size should be considered along with luminance contrast. Generally, for large character sizes (over 20 minutes of arc), the luminance contrast may be reduced.

b. References: Requirements

1. Bassani (1980): If the luminance contrast is too small, the display characters will blend into the background; and if the ratio is too large, the display characters will appear blurred. The contrast should be between 60% and 95%. Under high ambient light conditions, the range will be restricted from 40% to 70%. The range will be restricted from 60% to 90% under very low ambient light conditions.

2. Elke et al. (1980): A luminance contrast of 88% is recommended, although 94% is preferred.

3. Hemingway et al. (1979): The symbol-to-background contrast ratio should be above 10:1, but it should not exceed 45:1.

4. Shurtleff (1980): A contrast ratio of 10:1 is generally accepted as the industrial standard for display design. For general display conditions, the minimum acceptable contrast ratio is in the range of 10:1 to 18:1. The minimum acceptable ratio can be as low as 2:1 when the absolute luminance is 10 fL or greater and when the symbol size is 10 minutes of arc or greater. The minimum contrast ratio can be only as low as 5:1 when the absolute luminance is low (i.e., in the range of 0.01 to 0.1 fL) and when the symbol size is 20 minutes of arc or greater.

5. Woodson (1981): The contrast ratio should be as near 90% as possible.

2.2.1.6.3 Ambient Illumination

a. IOS Design Recommendation

The ambient illumination (illuminance) in the CRT area should be consistent with the requirements for the other visual functions, such as setting controls, reading instruments, inspecting maps, and performing various maintenance and housekeeping tasks. However, it should not interfere with the visibility of the signals on the CRT display. In general, the ambient illumination should be below the luminance level of the CRT background. It is recommended that ambient illumination not exceed 25% of screen luminance through diffuse reflection and phosphor excitation. When the detection of faint signals is required and when the ambient illuminance may be above 0.25 fc (2.7 lux), the CRT scopes should be hooded, shielded, or recessed. In some instances, filters may be effectively used, but they may reduce the luminance of the screen. Under low ambient light conditions, light signals on a dark background should be used, whereas dark signals on a light background are preferred under medium and high ambient illumination levels. The visibility of near-threshold signals can be maximized by visually adapting the viewer to the luminance level of the CRT. Whenever possible, a pre-exposure duration of at least 2 1/2 min. should be provided.

b. References: Requirements

1. Elke et al. (1980): Ambient illuminance should not contribute more than 25% of screen luminance through diffuse reflection and phosphor excitation. Under low ambient light conditions, light symbols on a dark background should be used; and under medium and high ambient illumination levels, dark symbols on a light background should be used. In general, the ambient illumination should be below the luminance level of the CRT background. To maximize the visibility of near threshold targets, the viewer should be visually adapted to the luminance level of the CRT. If possible, a 2 1/2-min. pre-exposure duration should be used.

2. MIL-HDBK-759A (1981): CRT luminance should be compatible with the ambient illumination required in the work area, except that shielding, filtering, or use of a hood may allow lower CRT luminance if the technique used is compatible with the viewer's task. Ambient illuminance should not contribute more than 25% of screen luminance through diffuse reflection and phosphor excitation.

3. MIL-STD-1472C (1981): The ambient illuminance in the CRT area should be appropriate for the other visual functions (e.g., setting controls, reading instruments, maintenance), but it should not interfere with the visibility of signals on the CRT display. Ambient illuminance should not contribute more than 25% of screen luminance through diffuse reflection and phosphor excitation. When the detection of faint signals is required and when the ambient illuminance may be above 2.7 lux (0.25 fc), scopes should be hooded, shielded, or recessed. A suitable filter may be employed in some instances, subject to approval of the procuring activity.

4. Woodson (1981): Ambient illuminance should not contribute more than 25% of the screen luminance through diffuse reflection and/or phosphor excitation. In the CRT area, the ambient illuminance should have appropriate intensity and color with respect to other visual tasks, such as setting controls, reading instruments, inspecting maps, and performing various maintenance and housekeeping tasks; but it should not interfere with the visibility of signals on the CRT display.

2.2.1.7 CRT Border Size

a. IOS Design Recommendation

Border size refers to the distance between the outer characters of a display and the edge of the display. A border is present only when the outer characters of a display are enclosed on all sides by an area perceptually different from the background and edge of the display. Displays with borders that are properly dimensioned are more attention-getting than are borderless displays. Borders should be between 50% and 150% of the height of capital letters.

b. Reference

Bassani (1980) provided this recommendation.

2.2.1.8 Glare

a. IOS Design Recommendation

Glare should be minimized and should not be objectionable to the viewer. Any number of techniques may be used to reduce glare, such as (a) use of a CRT hood or shield; (b) positioning light sources at least 60^0 outside of the viewer's central visual field; (c) use of a circularly polarized filter for cancelling light reflected off the CRT faceplate; (d) use of a cross-polarized lighting system that uses a polarizing filter over the CRT rotated 90^0 with respect to a polarizing filter over the light source; (e) use of a controlled white-light system, which delivers light to only the necessary work areas and baffles it from the CRT; (f) use of a selective-spectrum lighting system, in which the spectral output of the CRT is well outside the spectrum of ambient illumination; (g) application of an antireflective coating on the CRT faceplate and nonbonded filter surfaces; and (h) use of indirect lighting, which diffuses the light and distributes it evenly over the work area. The technique used to reduce glare should not significantly reduce luminance contrast between the CRT signals and the background luminance. An individual's increased sensitivity to glare with advancing age should be considered in the application of glare-reduction techniques.

b. References: Requirements

1. Bassani (1980): There are three types of display glare: (a) unwanted light reflected from the display, (b) light contrast between the display and its surroundings, and (c) a very bright light source adjacent to the display. Luminance contrast for the second and third types of glare should not be greater than (a) 67% between the display and its surroundings, (b) 90% between the display and remote surfaces, (c) 85% between the display and adjacent luminaires, and (d) 98% between any objects of the visual field of view.

2. Booth and Farrell (1979): Reflections from the CRT faceplate can range from bothersome to debilitating. In many applications, the effects of reflections can be substantially reduced or eliminated by proper design of room lighting and the use of protective hoods for the displays. To reduce reflections in critical applications, it may be desirable to have the display operators wear dark clothing. A system of illumination involving the partial collimation of overhead illumination is another technique used to reduce or alleviate reflection problems.

3. Elke et al. (1980): Reflected glare should be minimized by the proper placement of the CRT screen in relation to the light source. The light source should not be placed within 60° of the viewer's central field of view. The light should be diffused and distributed evenly over the work area, and the ratio between the light and dark portions of work surface should not exceed 7:1. In addition, glare should be minimized by (a) proper placement of the CRT scope relative to the light source, (b) use of a hood or shield, (c) optical coatings or filters over the light sources, or (d) directional or spectrum filters.

4. IBM Corporation (1979): Disability glare and discomfort glare can be minimized by increasing the angular separation between the line of sight and the glare source. Also, an individual's sensitivity to discomfort glare increases with age.

5. MIL-HDBK-759A (1981): Reflections and glare from CRT faceplates and cover plates should be minimized by employing one or more appropriate techniques, such as (a) shielding the CRT; (b) positioning light sources so they do not reflect off the CRT faceplate into the viewer's eyes; (c) use of a circularly polarized filter for cancellation of light reflected off the CRT faceplate; (d) use of a cross-polarized

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lighting system (a polarizing filter over the CRT, rotated 90° with respect to polarizing filters over the light sources); (e) use of a controlled white-light system, which delivers light only to the necessary work areas and baffles it from the CRT; (f) use of a selective-spectrum lighting system, wherein the spectral output of the CRT is substantially outside the spectrum of ambient illumination; and (g) application of an antireflective coating on the CRT faceplate and nonbonded filter surfaces to reduce the proportion of reflected light.

6. MIL-STD-1472C (1981): Reflected glare should be minimized by (a) the proper placement of the CRT scope relative to the light source, (b) the use of a hood or shield, or (c) the use of an optical coating or filter over the light source.

7. Woodson (1981): When very faint signals must be detected, viewing hoods or glare-reduction devices should be used; and/or a suitable light control filter should be used to maximize the ratio of the CRT signal to background luminance.

2.2.1.9 Adjacent Surfaces

a. IOS Design Recommendation

All surfaces adjacent to the CRT should have a dull matte finish, and the luminance range of these surfaces should be between 10% and 100% of the screen background luminance. If possible, a means for adjusting the surrounding luminance should be provided to ensure operation within this range. Except for emergency indicators, light sources in the immediate surrounding area should not be brighter than the CRT signal luminance.

b. References: Requirements

1. Bassani (1980): Luminance contrast should not exceed (a) 67% between the display and its surroundings, (b) 90% between the display and remote surfaces, (c) 85% between display and adjacent luminaires, and (d) 98% between any objects within the visual field of view.

2. Elke et al. (1980): All surfaces adjacent to the CRT should have a dull matte finish.

3. MIL-HDBK-759A (1981): Panel surfaces adjacent to the CRT should have a dull matte finish, with a luminance range between 10% and 100% of the screen background luminance under ambient operational conditions. If necessary, a means for adjusting the surround luminance should be provided to ensure operation within this range.

4. MIL-STD-1472C (1981): Surfaces adjacent to the CRT should have a dull matte finish. The luminance of the light reflected from these surfaces should be in the range of 10% to 100% of the CRT screen background luminance. Light sources in the immediate surrounding area, except emergency indicators, should not have a luminance greater than the scope signal.

5. Woodson (1981): The luminance of surfaces immediately adjacent to scopes should be in the range of 10% to 100% of the screen background luminance. Except for emergency indicators, light sources in the immediate surrounding area should not be brighter than the scope signals.

2.2.1.10 Flicker

a. IOS Design Recommendation

The refresh rate of CRT displays should be in the range of 50 to 65 Hz as required, or above the viewer's critical fusion frequency, so that flicker is not perceptible. Rapid eye movements while reading displayed text increases flicker sensitivity. The type of phosphor used, as well as the temporal light-to-dark ratio, influences the perception of flicker. A large area will appear to flicker sooner than a small area, and a brighter light will appear to flicker sooner than a dimmer light. The interlace refresh technique may be used to reduce or eliminate flicker. This technique utilizes a CRT image that is divided in half; one half is then refreshed during one refresh cycle, and the other half is refreshed on the next cycle. Display flicker may be useful for alerting the viewer (blink or flash coding). Blink codes should be between 1 and 7 Hz.

b. References: Requirements

1. Bassani (1980): Flicker occurs when a light source turns on and off at a rate at which the human eye can perceive that the light is not on continuously. Display flicker is acceptable only when it is used to alert the user. The refresh rate of a rapid-decay display medium should be about 60 Hz. The human eye is particularly sensitive to flicker in two situations. The first is when displayed text must be read. Rapid eye movements while reading the text increase flicker sensitivity. The second is when the light-to-dark ratio is about 0.03 (97% in darkness) for a bright display. Under these conditions flicker detection ability is maximized. The refresh rate for slow-decay displays may be lower.

2. Elke et al. (1980): The regeneration rate for a particular display depends on a variety of variables, but generally, it should be above the viewer's critical fusion frequency so that flicker is not perceptible.

3. IBM Corporation (1979): If the refresh rate is sufficiently high (about 65 Hz or greater), the display will appear to be steady and nonflickering. Most CRT visual display units, including television, have refresh rates considerably less than 65 Hz. As a consequence, other factors that influence the perception of flicker (e.g., size, brightness, and waveform) come into play. All things being equal, a large area will appear to flicker before a small area does; and a brighter light will appear to flicker before a dimmer light. Display flicker occurring in a typical office lighting environment may not be perceived when the room lighting is lowered considerably and when the display brightness is also lowered. Another approach to reduce display flicker is to use the

interlace refresh technique. With this technique, the CRT image is divided in half; one half is refreshed during one refresh cycle, and the other half is refreshed on the next cycle. Thus, a CRT with a 40-Hz refresh rate, for example, that uses the interlace technique (80 half frames per sec.) might have the same resistance to flicker as a CRT that has a true 50-Hz refresh rate but does not employ the interlace technique. Waveform may also influence the perception of flicker. With respect to CRT phosphors, the term "persistence" is used rather than waveform.

4. MIL-HDBK-759A (1981): The refresh (repaint) rate of signals or data displayed on a CRT should be outside the range of 7 to 28 Hz. Refresh rates between 1 and 7 Hz should be used only to capitalize on the conspicuity value of the low rates, such as for warning signals or when flash (blink) coding is practical. The refresh rate for data that are to be perceived as being continuously presented should be above 28 Hz, as required to reduce flicker to below threshold across the entire range of display luminance levels.

5. Woodson (1981): Refresh rates should be compatible with the critical flicker frequency response of the eye. The particular phosphor/driver combination should not generate display rates in the 30- to 55-Hz range. For character displays, the refresh rate should be greater than about 30 to 40 Hz. With average display luminance values, some flicker may be detected unless the refresh rate is at least 50 Hz. Flicker will not be perceptible on TV at 60 frames per sec. unless the display luminance exceeds about 180 fL. If the display luminance is reduced to 30 fL, 50 frames per sec. is usually acceptable.

2.2.1.11 Phosphor

a. IOS Design Recommendation

The selection of CRT phosphors should take into consideration the requirements for color, persistence, display motion, resolution, and durability. Short-persistence phosphors with fast decay rates should be used for displays having high refresh rates and rapid image movements, to prevent the smearing of the images. Medium-persistence phosphors should be used when moderate image movement is required. Long-persistence phosphors are preferred when the display presents relatively static images or when the information update is relatively infrequent as in character and radar displays. The characteristics of the most commonly used phosphors are presented in Table 2-1.

Table 2-1. CRT Phosphor Applications and Characteristics (From MIL-HDBK-759A, 1981.)

Application	Phosphor[a]	CIE Coordinates		Persistence[b]	Fluorescence	Phosphorescence	Decay time (m sec)
		X	Y				
Radar	P1	.218	.712	Med.	Yellow Green	Yellow Green	24
Sonar,	P2	.279	.534	Med.	Yellow Green	Yellow Green	35-100
and	P7	.357	.537	Long	Yellow	Yellow Green	
Oscilloscope	P10			Very Long	Dark Trace	Screen	
	P12	.605	.394	Med. Short	Orange	Orange	
	P14	.504	.443	Med.	Yellow Orange	Orange	
		.150	.093	Med. Short	Blue	Orange	
	P17	.302	.390	Long	Blue	Yellow	
	P19	.572	.422	Long	Orange	Orange	
	P21	.539	.373	Med.	Red Orange	Red Orange	
	P25	.557	.430	Med.	Orange	Orange	
	P26	.582	.416	Very Long	Orange	Orange	
	P28	.370	.540	Long	Yellow Green	Yellow Green	500
	P29	(P2 + P25)		Med.	Green	Green	
	P31	.193	.420	Med. Short	Green	Green	4
	P32			Long	Purple Blue	Yellow Green	
	P33	.559	.440	Very Long	Orange	Orange	
	P34	.235	.364	Very Long	Blue Green	Yellow Green	40 sec
	P35	.286	.420	Med. Short	Green	Blue	
	P38	.561	.437	Very Long	Orange	Orange	1040
	P39	.223	.698	Long	Yellow Green	Yellow Green	150
	P40	.276	.3117	Med.	White/Blue	Yellow Green	
Monochrome TV	P4	.270	.300	Med. Short	White	White	25
	P23	.375	.390				
Color TV	P22	.155	.060	Med.	Blue	Blue	25
		.285	.600	Med.	Yellow Green	Yellow Green	60
		.675	.325	Med.	Orange Red	Orange Red	0.9

Table 2-1. CRT Phosphor Applications and Characteristics (Concluded)

Application	Phosphor[a]	CIE Coordinates		Persistence[b]	Fluorescence	Phosphorescence	Decay time (m sec)
		X	Y				
Projection TV	P18	.333	.347	Med.			
Storage Tubes	P20	.444	.536	Med. Short	Yellow Green	Yellow Green	

[a] Phosphor:

P1 - High efficiency, resolution and resistance to burn.
P2 - Decrease in decay with increase in beam current.
P4 - Sulfide version.
P7 - High efficiency and resistance to burn.
P19 - Slow refresh rate for flickerless display; low light output; low burn resistance.
P25 - Desired low-level persistence, high resistance to burn; low light output.
P26 - Slow refresh rate for flickerless display; low light output and burn resistance.
P31 - Curve has blue peak at 450 nm; high efficiency, resolution and resistance to burn.
P33 - Decay decreases with beam current decreases; burns rapidly when used with stationary or slow-moving beam.
P34 - IR stimulatable; Y-phosphor.
P35 - Resists burning compared to P11.
P39 - Similar to P1 but with longer decay.

[b] Persistence:

VL = Very Long, 1 s or over
L = Long, 100 ms to 1 s
M = Medium, 1 ms to 100 ms
M/S = Medium Short, 10 us to 1 ms
S = Short, 1 us to 10 us
VS = Very Short, less than 1 us

b. References: Requirements

1. Elke et al. (1980): The choice of CRT phosphor depends on the specific application, but generally, the phosphor should emit in the green region of the visible spectrum and reduce flicker. Short-persistence phosphors with decay rates of less than 10^{-3} sec. should be used for displays with high refresh rates and rapid image movements. Medium-persistence phosphors with decay rates not more than 0.1 sec. should be used with moderate image movement; and the long-persistence phosphors are best for radar displays where information update is relatively infrequent (i.e., between 30 sec. and several minutes apart).

2. IBM Corporation (1979): Phosphor persistence and the color of the light emitted by the display are two important considerations in the selection of a phosphor for a CRT. Phosphors with short persistence must be refreshed more times per second than phosphors with longer persistence. TV requires a phosphor with short persistence so that the images in motion on the screen will not be smeared. CRT displays that present relatively static images may take advantage of the longer-persistence (slow-decay) phosphors because image blurring is not a problem. The commonly used phosphor in black-and-white (monochromatic) TV is P4, and the three P22 phosphors (P22G-Green, P22B-Blue, and P22R-Red) are commonly used in color TV.

3. MIL-HDBK-759A (1981): The selection of CRT phosphors should be made on the basis of color, persistence, resolution, capability, and durability as appropriate to the viewer's task when using the CRT. The characteristics of commonly used phosphors currently available are shown in Table 2-1.

4. Woodson (1981): For alphanumeric and/or discrete image displays that change frequently, P4 and P7 phosphors are recommended.

2.2.1.12 Phosphor Persistence

a. IOS Design Recommendation

The persistence of phosphor is determined by the length of time the phosphor remains illuminated after the CRT electron beam has excited it. Phosphor persistence has an effect on how many times per second the display must be refreshed so that it appears to be continuous rather than flickering. Short-persistence phosphors must be refreshed more frequently than phosphors with longer persistence. Although long-persistence phosphors allow reduced refresh rates without causing the display image to flicker, the increased persistence may result in image smear and afterimages, which make the display unacceptable for moving targets. For alphanumeric and/or discrete image displays that change frequently, P4 and P7 phosphors are recommended. Displays should be designed to minimize the burning of long-persistence phosphors because burned areas degrade display legibility. Antiburn techniques, such as aluminized screen backings and automatic intensity-reducing circuits, may be used to prevent burning as appropriate.

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b. References: Requirements

1. Booth and Farrell (1979): Long-persistence phosphors allow reduced refresh rates without causing the display image to flicker. However, increased persistence may cause smear and afterimages, which make the display unacceptable for moving images.

2. Elke et al. (1980): Medium-persistence phosphors with decay rates not exceeding 0.1 sec. should be used with moderate image movement; and long-persistence phosphors should be used for radar displays where the information update rate is relatively infrequent (i.e., between 30 sec. and several minutes apart).

3. MIL-HDBK-759A (1981): Displays using transient signals with very short durations, such as in radar and sonar systems, should have sufficient persistence for the viewer to perform the task required relative to the signals. Persistence beyond the signal duration may be achieved by using persistent phosphors, periodic refreshing of the display image, scan converters, or direct-view storage tubes, as appropriate. For rotating sweep displays, persistence should at least allow even faint signals to be displayed above threshold for a period equal to one quarter of a sweep rotation. Short to medium persistence is adequate for scan rates such as those used with television. Caution should be exercised in the design of a display to prevent the burning of long-persistence phosphors, such as P19, P25, and P33, because burned areas seriously degrade display legibility. Antiburn techniques that may be used include aluminized backings and protective circuits for automatically reducing the intensity of a stationary beam.

4. Woodson (1981): The absolute minimum persistence for target detection tasks is 0.1 sec., but 2 to 3 sec. is much preferred. The general rule is that display images should not persist beyond the time required for the eye to detect the presence of the target, because long persistence only confuses the image. For alphanumeric and/or discrete image displays that change frequently, P4 and P7 phosphors are recommended.

2.2.1.13 Screen Shape

a. IOS Design Recommendation

The screen shape for the presentation of television-type images should be rectangular, with a width-to-height aspect ratio of 4:3. Character displays should have screen shapes with ratios of 5:7 or 2:3 to provide maximum legibility. As a general rule, the shape of the CRT should be compatible with the type of information to be displayed.

b. References: Requirements

1. MIL-HDBK-759A (1981): The display surfaces of CRTs that are used exclusively for data presentation of computer graphics should be rectangular in shape. CRT displays used exclusively for the presentation of television images should also be rectangular and should normally follow the standard practice of having a 3:4 height-to-width aspect ratio. CRTs

that are used exclusively for polar plots of sensor data should be round. For A-scan presentations, the preferred display shape is rectangular. CRT displays used simultaneously or sequentially for two or more different display functions may have round, square, or rectangular surfaces, as best serves the combined purpose.

2. Woodson (1981): The standard television display width-to-height aspect ratio is 4:3, but the greatest legibility is provided by ratios of 5:7 or 2:3. The shape of the CRT should be compatible with the type of information displayed: (a) round for plan position indicator (PPI) displays; and (b) rectangular for A-scan presentations, document images, and so forth.

2.2.1.14 Screen Size

a. IOS Design Recommendation

The recommended screen size depends on the specific applications of the display, such as for television images, alphanumerics, signal detection, tracking, tactics, and single characters. In general, the overall size of the screen should be determined on the basis of the smallest significant detail size that must be visually resolved by the eye from the expected viewing distance and on the basis of the intended number of characters to be displayed with a legible size and format. The recommended diagonal size of the CRT screen for typical console viewing distances is 304.8 to 482.6 mm (12 to 19 in.).

b. References: Requirements

1. Elke et al. (1980): The screen size should be a 12-in. diagonal for a single seated viewer at a 28-in. viewing distance. This size is recommended for both console-based CRTs and CRTs used in flight control.

2. IBM Corporation (1979): The usable area of the display surface should be large enough to display the intended number of symbols in a legible size and format.

3. MIL-HDBK-759A (1981): The diameter of direct-viewing, console- mounted CRTs should normally be within the following limits:

(a) Television: 120-mm minimum; 600-mm maximum.

(b) Alphanumeric displays: size these by considering the largest format that will be required and the recommended character size.

(c) Single-character displays: 20-mm minimum.

(d) For detection of signals from sensor systems: 215 mm ± 40 mm.

(e) For both detection and tracking: 300 mm ± 50 mm.

(f) Tactical or situation displays: 380-mm minimum; 760-mm maximum.

(g) Display of single pulse or short sweep segments for qualitative monitoring only: 20-mm minimum.

The CRTs for detection, detection and tracking, and situation display (d, e, and f above) may be smaller when there are severe space constraints, such as in aircraft, submarines, or hand-held units.

4. Shurtleff (1980): A procedure for determining CRT size for specific workstation applications is presented. To utilize this procedure, the designer must know in advance how many rows of characters are to be displayed and how many characters per row are required by the display user. The first step in determining the required CRT size is to plot two viewing envelopes: (a) the effective viewing area and (b) the required viewing area for the CRT display. These plots show the on-line viewing distance. The next step is to determine the absolute height of the symbol that is needed on the CRT for the viewing distance. Next, it is necessary to determine the width of the CRT, which is computed on the basis of the required number of characters per row, symbol width, and spacing between symbols. Next, the height of the CRT is determined, which is calculated on the basis of the required number of character rows, symbol height, and spacing between adjacent rows. Following the determination of the tube size and character size requirements, the total resolution requirements of the display must be computed. The overall resolution requirements for dot matrix CRT displays are based on several factors: the size of the dot matrix used to construct the alphanumeric characters, the dot spacing between symbols in a row, the dot spacing between rows, and the total number of rows and characters per row needed. This procedure is described with examples for general industrial use, for CRT consoles in military systems, and for CRT displays for group or remote viewing.

5. Woodson (1981): The overall size of the CRT screen should be determined on the basis of the smallest significant detail size that must be visually resolved by the eye from the expected viewing distance. The recommended diameter of the CRT tube is as follows:

(a) For plan position target search operations: 7-in. (18-cm) minimum.

(b) For central-area target detection efficiency: 10 to 14 in. (25 to 36 cm).

(c) For typical console operator viewing distances (all signal types): 12 to 19 in. (30 to 48 cm).

Larger tube sizes may be used for television-type viewing and status-board displays that may be viewed by several operators. Tube sizes larger than 48 in. (122 cm) are not recommended, because of the loss of brightness and contrast as the viewers are required to view the screen from a greater distance.

2.2.1.15 Distortion

a. IOS Design Recommendation

Distortion refers to the perceived departure from straightness of a line displayed on a CRT. Alphanumerics or graphics should have no perceptible distortion in any column or row of characters, and the size of the characters should appear to the viewer to be the same across all parts of the display unless different sizes are intentionally used.

b. References: Requirements

1. Elke et al. (1980): The total geometric distortion should not displace any point on the display from its correct position by more than 2% to 5% of the picture height.

2. MIL-HDBK-759A (1981): CRT displays presenting only alphanumerics or graphics should have no detectable distortion in any column or row of characters, and the aspect ratio of the characters should appear constant across all parts of the display screen. Sweep nonlinearity with raster on PPI-type scans should not exceed 2%.

3. Woodson (1981): The displacement of an image element should not exceed 2% of the image height.

2.2.1.16 Blur

a. IOS Design Recommendation

Blurring of display symbology is the perceived effect of defocusing of the CRT electron beam. Defocusing occurs because of the inability to precisely position the beam at all points on the surface of the CRT. When the beam is focused to provide the maximum sharpness at the center of the CRT, the beam will be blurred to some extent at the periphery of the CRT, and vice versa. Therefore, the CRT will typically be adjusted to provide the best overall focus and to minimize defocusing over the surface of the CRT. The use of larger size symbols and higher contrast will minimize the adverse effects of excessive blur resulting from the defocusing of the CRT beam. Increases in symbol stroke widths up to 20% from beam defocusing will probably have a negligible effect on identification accuracy and no effect on speed of identification.

b. Reference

The design recommendation was obtained from Shurtleff (1980).

2.2.1.17 Signal-to-Noise Ratio

a. IOS Design Recommendation

The signal-to-noise ratio should be large enough to achieve the objectives of the video system. In general, a signal-to-noise ratio of 10:1 is considered satisfactory, 30:1 is considered good, and 50:1 is considered excellent.

b. Reference

This recommendation is from Elke et al. (1980).

2.2.1.18 CRT Response Time

a. IOS Design Recommendation

The time from the initiation of a computer output to the appearance of a new CRT display page should not be longer than 1 to 3 sec.

b. Reference

Elke et al. (1980) provide this design stipulation.

2.2.1.19 Graphics

a. IOS Design Recommendation

To give the appearance of continuity, there should be at least 20 points per cm (50 per in.) for lines used in display graphics.

b. References: Requirements

1. Elke et al. (1980): Lines used in graphics should have at least 20 points per cm (50 points per in.) to give the appearance of continuity.

2. Woodson (1981): CRT point resolution is conventionally a fixed percentage of the display size. For example, resolution is about 85 points per in. (1023 x 1023 per display surface) on a 12-in. (30-cm) CRT. In contrast, a 4-ft. (1.2-m) display with the same matrix would have a resolution of about 21 points per in. Although this has little effect on alphanumeric data, it puts a definite limitation on CRT graphics. Line thickness is also proportional to the display area in both CRT and large-screen displays.

2.2.2 Special Requirements for Color CRT Displays

Principles and guidelines for the use of color as a display code in CRT applications were developed by Krebs, Wolf, and Sandvig (1978) from an extensive review of the scientific literature. These principles and guidelines are presented in this section.

2.2.2.1 Symbol Size

Small symbols may appear to be achromatic, and similar colors of small symbols may be confused. Consequently, colored display symbols should be larger than achromatic symbols.

a. Symbol Height: The minimum height for alphanumerics to ensure adequate color perception is 21 minutes of arc. As the number of colors used is increased from 2 to 6, the minimum height should be increased to about 45 minutes of arc. The size should be increased above the minimum recommended levels when luminance contrast is low or when the display is degraded by noise and/or poor resolution. Symbol size should be increased as symbol luminance decreases.

b. Symbol Width: The width-to-height ratio for color symbols should be 5:7 or 2:3.

c. Stroke Width: The minimum stroke width for color CRT symbols is 2 minutes of arc.

d. Line Width for Display Graphics: The minimum line width for CRT graphics is 4 minutes of arc.

2.2.2.2 Resolution

Resolution is typically defined in terms of lines per symbol height for raster scan CRT displays. For matrix or LED displays, the resolution requirements are specified as the number of dots or strokes per character.

a. Raster Scan Displays: A minimum of 15 scan lines per symbol height is required for colored symbols.

b. Matrix Displays: In general, a larger dot format should be used rather than smaller, brighter dots. A 5 x 7 dot matrix will provide marginal performance; therefore, larger matrix sizes should be used whenever possible for color symbols.

2.2.2.3 Display Luminance and Contrast

The required luminance of color symbols depends on a variety of factors, the most important being background luminance, ambient illumination, and symbol size. The color of the symbols is also important at very low symbol luminances and under very high ambient lighting conditions.

a. Symbol Luminance: The minimum luminance of color symbols should be about 3 cd/m^2 to provide for good color perception. The optimum luminance under moderate lighting conditions is in the range of 30 to 300 cd/m^2.

b. Background Luminance: The visibility of color symbols is better on a dark background than on a light background. For achromatic black-and-white displays, the opposite is preferred.

c. Contrast: The optimum symbol-to-background luminance ratio for CRT displays is about 10:1. If this value cannot be achieved, the values of the other display design factors should be adjusted to compensate for the use of nonoptimum values; that is, increase the symbol size and/or reduce the number of colors used.

d. Ambient Illumination: Ambient illumination reaching the display surface reduces symbol-to-background contrast. Colors will begin to desaturate, or fade, and they may be completely washed out under very high ambient lighting conditions. Conversely, if the ambient lighting is very low, the minimum symbol luminance may have to be used to maintain dark adaptation. However, if the symbols are colored, reducing their luminance below about 3 cd/m^2 will seriously impair their color perception. Consequently, if either very low or very high ambient illumination is likely in the range of display applications, color should probably be used as a redundant code.

2.2.2.4 Display Location and Peripheral Vision

The location of displays relative to the visual field of the viewer can affect the detectability of color symbols. Color detection is best when the display is centrally located (foveal displays) and poorest when the display is located in the periphery (peripheral displays). The limits of color sensitivity are shown in Figure 2-4.

a. Foveal Displays: A display can be considered to be foveal under the following circumstances: (a) when it is the only display the viewer must use, and it is very small, about 3° or 4° of visual angle; or (b) when it is actively and frequently scanned by the viewer; or (c) when it is one of several displays actively and frequently scanned by the viewer; or (d) when it is located in the viewer's normal line of sight.

b. Peripheral Displays: A display must be considered peripheral under the following conditions: (a) when it is one of many displays, and is outside the viewer's normal scan pattern, or (b) when it is larger than 3° or 4° of visual angle and portions of it are seldom scanned.

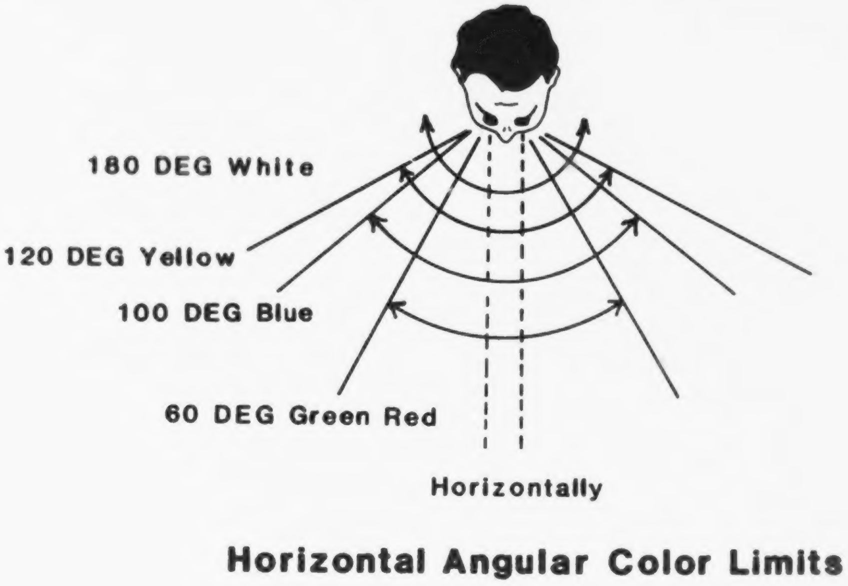
2.2.2.5 Display Color Selection

The selection of color codes for displays involves determining how many colors will be used and what these colors should be.

a. Number of Colors: The number of colors to use in a display should take into account the limitations of the display medium, the ambient lighting, and the viewer's perceptual limitations. For operational displays, only three or four colors are recommended if ambient lighting is expected to be high at times, if display reliability may be limited, and if fast viewer reaction times are critical.

1. Display Medium: As the number of colors and the similarity between the colors in a display increase, the greater is the need to precisely define and reproduce the colors on the display.

2. Perceptual Limits: Ten colors appear to be the maximum for good detection accuracy when absolute color identification is required. More colors may be used if absolute identification is not required. For example, where color serves as an aid to search on surface color maps, up to 23 colors can be used. The general rule to follow is that as the number of colors is increased, where each color has a particular meaning, both color detection errors and detection time increase.


180 DEG White
120 DEG Yellow
100 DEG Blue
60 DEG Green Red
Horizontally
Horizontal Angular Color Limits

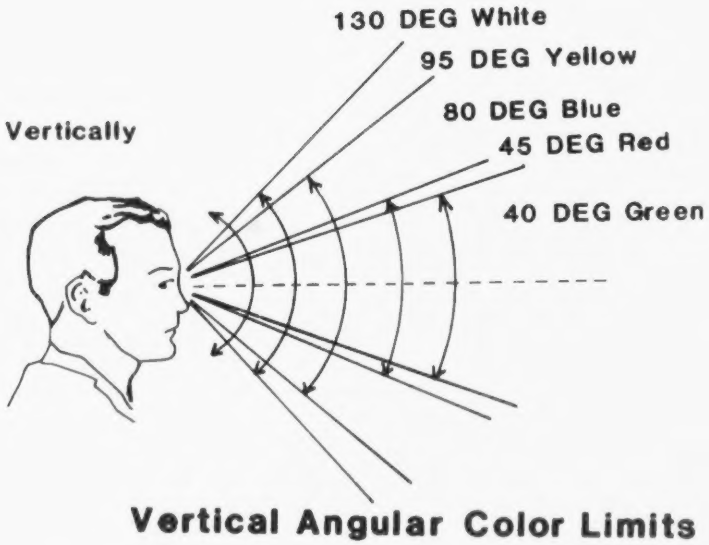

130 DEG White
95 DEG Yellow
80 DEG Blue
45 DEG Red
40 DEG Green
Vertically
Vertical Angular Color Limits

Figure 2-4. Horizontal and Vertical Angular Color Limits. (From Krebs, et al., 1978.)

b. Color Variety: The best single criterion to use in selecting a set of colors is to choose colors that are as widely spaced in wavelength as possible along the visible spectrum. Other criteria for selecting a specific color are (a) high color contrast, (b) high visibility in the specific application, (c) compatibility with conventional use and meaning, (d) legibility and ease of reading, and (e) high saturation. The recommended color set for a 6-color and 10-color code are shown respectively in Tables 2-2 and 2-3.

1. Color Visibility: Not all colors are equally visible. Small symbols or fine detail are not well detected in blue. Consequently, blue is not recommended for alphanumerics, lines, and so forth, unless they are very large. Under certain conditions, display symbols that are red, white, or yellow can be read at a faster rate than green or blue symbols.

2. Conventional Color Codes: Color displays should be designed to capitalize on conventional color usage when appropriate. For example, the colors red, green, and yellow are generally used to signify warning, safe or advisory, and caution, respectively.

3. Color Saturation: Generally speaking, highly saturated colors should be used to maximize the differences among colors. In some situations, however, it may be desirable to use color saturation as a coding dimension. This code might be used for displays that provide only a limited number of colors but offer a different saturation level for each color. Changes in saturation should not produce colors that are difficult to detect under the expected range of viewing conditions. For example, the visibility of a desaturated color may be seriously degraded when there is high ambient illumination on the screen surface, which tends to desaturate or wash out the color of a symbol.

Table 2-2. Recommended Colors for a 6-Color Code (From Krebs et al., 1978.)

Color name	Dominant wavelength (nm)
Purple	430
Blue	476
Green	515
Yellow	582
Orange	610
Red	642

Table 2-3. Recommended Colors for a 10-Color Code (From Krebs et al., 1978.)

Color name	Dominant wavelength (nm)
Violet	430
Blue	476
Greenish-Blue	494
Bluish-Green	504
Green	515
Yellow-Green	556
Yellow	582
Orange	596
Orange-Red	610
Red	642

2.2.2.6 Color Coding

In some situations, color coding is superior to other codes. Color coding is beneficial when (a) the display is unformatted, (b) symbol density is high, (c) the viewer must search for the relevant information, (d) symbol legibility is degraded, and (e) the color code is logically related to the viewer's task. Color should be used to aid the viewer in locating particular information and to draw attention to some specific place or symbol. In comparison, alphanumerics should be used to convey specific status information and to identify specific targets.

2.2.2.7 Multidimensional Coding

Color can be used in combination with a variety of other codes to provide additional information or to make existing information easier to see or use. The most frequently used codes are alphanumerics, shape, symbol orientation, symbol size, and symbol brightness. Multidimensional codes should be used to convey specific information that cannot otherwise be conveyed and to increase the amount of information that can be displayed. Color codes used along with other codes may be fully redundant, partially redundant, or nonredundant. Krebs, et al. (1978) provide the following example to clarify full and partial redundancy:

> "A hypothetical digital readout has nine possible values it can assume. If color were fully redundant with numeric value, then each of the nine digits would be associated with one of nine different colors. Knowing the color of the symbol would provide full knowledge of the numeric value and vice versa.
>
> "If, however, several numbers were associated with the same color, such that for example the three lowest values were

> coded yellow, the three middle values green, and the three highest values red, then the color code would be partially redundant with the numeric code. That is, knowing the symbol color would give only partial information about its numeric value. Knowing that the symbols displayed were green would indicate that the numeric value was one of three intermediate values.
>
> "A third form of multiple coding involves use of two or more codes in a situation where each conveys unique information not contained in the other codes. Such coding is nonredundant."

a. Fully Redundant Codes: The display designer may use fully redundant codes to improve symbol detectability and to aid in discriminating among symbols. The preferred combined code appears to be color and shape.

b. Partially Redundant Codes: When information can be categorized at more than one level of specificity, partially redundant codes may be used. For example, alphanumerics may be used for specific display parameters (e.g., engine RPM and fuel flow), and color may be used to identify a logical grouping of parameters (e.g., all engine instruments would be given the same color code).

c. Nonredundant Codes: The designer may use nonredundant codes to increase the total number of symbols that may be identified. For example, targets on a display could be coded by color as either friendly or hostile. Target type, such as aircraft and land vehicles, could be coded by shape. Also, specific targets within a type could be coded alphanumerically.

2.2.2.8 Irrelevant Color Coding

Color codes that are irrelevant to the viewer's task may provide no benefit or they may interfere with task performance. Color provides no performance benefits when the viewer's task is easy and/or the display is uncluttered. Color coding can degrade performance by serving as a distractor if the task is difficult and the color code is inappropriately related to the operator's task. Thus, color should be used as an aid for the most frequent or the most difficult tasks. Colors that serve no definable task function should be avoided.

2.2.2.9 Display Density

Display density refers to the number of symbols on a display. To the extent that the target position is unknown on an unformatted display, non-target symbols serve as "noise," which will distract the viewer. The use of color coding in high-density displays will reduce target search time if the target position is unknown and if the target color is known. However, if the target color is unknown, target search time will increase. In addition, color coding can be used to minimize the effects of high symbol density by presenting functionally related items in the same color or by presenting "target" data, such as a warning signal, in a unique and prespecified color.

2.2.3 Special Requirements for Television (TV) Displays

2.2.3.1 Monochrome and Color TV

2.2.3.1.1 Resolution

a. IOS Design Recommendation

The minimum display resolution is 400 lines both horizontally and vertically. Line spacing need not be closer than 1 minute of arc in low-resolution applications.

b. References: Requirements

1. MIL-HDBK-759A (1981): Display resolution should be 400 lines or greater both horizontally and vertically. For low-resolution applications, line spacing need not be closer than a visual angle of 1 minute of arc.

2. Woodson (1981): The horizontal and vertical resolution limits of color picture monitors are provided in Table 2-4.

Table 2-4. Resolution Limits for Color Picture Monitors (From Human Factors Design Handbook (p. 543) by W.E. Woodson, 1981, New York, NY: McGraw-Hill, Inc. Copyright 1981 by McGraw-Hill, Inc. Reprinted by permission.)

Video signal	Vertical resolution Center (lines)	Vertical resolution Corner (lines)	Horizontal resolution Center (lines)	Horizontal resolution Corner (lines)
Monochrome	400	400	800	700
Red, Green, or Blue	400	400	800	700

2.2.3.1.2 Character Size

a. IOS Design Recommendation

The number of TV raster lines per character height should be in the range of 10 to 18, to provide maximum legibility. With high-quality TV (i.e., a minimum of 945 lines), readability is good at 6 lines. A minimum of 15 lines per character height is recommended for group TV viewing when small visual angles are involved.

b. References: Requirements

1. Elke et al. (1980): Critical targets and targets of complex shape that are to be distinguished from complex, nontarget shapes should subtend a minimum of 20 minutes of arc, with a resolution of at least 16 to 17 lines per symbol height.

2. MIL-STD-1472C (1981): A target of complex shape that is to be distinguished from a complex, nontarget shape should subtend a minimum of 20 minutes of arc and a minimum of 10 lines or resolution elements.

3. Shurtleff (1980): The minimum number of lines per symbol height should be in the range of 12 to 18 for maximum identification accuracy and speed.

4. Woodson (1981): The quality of TV equipment has negligible effects on the accuracy or speed with which standard alphanumerics at 8, 10, and 12 lines can be read. With high-quality TV (i.e., a minimum of 945 lines), readability is good at 6 lines. A minimum vertical resolution of 15 lines per character is recommended for group TV viewing when small visual angles are involved. With 15 lines per symbol height, the recommended maximum viewing distances for various TV monitor sizes are as follows:

(a) 17-in. (43-cm) monitor - 11 ft. (3.4 m).
(b) 21-in. (53-cm) monitor - 13 ft. (3.9 m).
(c) 24-in. (61-cm) monitor - 15 ft. (4.6 m).
(d) 27-in. (69-cm) monitor - 18 ft. (5.5 m).

For viewing pictorial TV, the recommended maximum viewing distances for various TV monitor sizes are as follows:

(a) 9-in. (23-cm) monitor - 18 to 30 in. (46 to 76 cm)
(b) 15- to 17-in. (38- to 43-cm) monitor - 30 in. to 6 ft. (76 cm to 1.8 m)
(c) 17- to 19-in. (43- to 48-cm) monitor - 6 to 10 ft. (1.8 to 3.1 m)
(d) 19- to 23-in. (48- to 58-cm) monitor - 10 to 20 ft. (3.1 to 6.1 m)
(e) 21- to 30-in. (53- to 76-cm) monitor - 20 to 30 ft. (6.1 to 9.2 m)

2.2.3.1.3 Gray Scale Levels

a. IOS Design Recommendation

The number of gray scale levels should be in the range of 5 to 10. The upper limit of the range should be used when there is a requirement for the interpretation of handwriting, resolution of fine detail, complex image interpretation, target recognition, and realistic TV images. For most digitally generated images, a single (black-and-white) level is acceptable.

b. References: Requirements

1. Elke et al. (1980): At least 10 shades of gray should be used to ensure target recognition and to provide realistic TV images.

2. MIL-HDBK-759A (1981): A minimum of five distinguishable gray scale levels should be used. Up to eight gray scale levels should be provided when the interpretation of handwriting, resolution of fine detail, or complex image interpretation is required.

3. Woodson (1981): A minimum of five gray scale levels should be provided for TV. For most digitally generated images, a single (black-and-white) level is acceptable.

2.2.3.1.4 Video Bandwidth

a. IOS Design Recommendation

The current video bandwidth standard for TV display systems is well above the minimum needed for accurate identification performance. For color TV, a video bandwidth of 4.5 MHz should be used; for monochrome TV, the video bandwidth should be 10 MHz.

b. References: Requirements

1. Shurtleff (1980): The current TV standard, which provides video bandwidths of 4 to 5 MHz or greater, is well above the minimum needed for high accuracy of identification. TV data displays should not be used for closed-circuit TV systems with bandwidths below 4 MHz . When display symbols are constructed by a symbol generator, rather than from input from a TV camera for digital TV, the bandwidth requirements can be determined as follows:

$$f = 0.712\ pn^2N$$

Where f = bandwidth
p = aspect ratio of scanning lines
n = the number of lines needed to meet symbol capacity requirements
N = frame rate

TV data displays for analog TV systems with bandwidths below 4 MHz will require excessive vertical resolution of up to 17 lines in order to maintain a high level of identification performance. The minimum requirement for 10 to 12 scan lines per symbol height will not be lowered, however, by using high-bandwidth TV systems.

2. Woodson (1981): A bandwidth in the range of 4 to 10 MHz is acceptable. For color picture signal transmission, a video bandwidth of 4.5 MHz should be used. For monochrome picture signals, the video bandwidth should be 10 MHz.

2.2.3.1.5 Frame Rate and Interlacing

a. IOS Design Recommendation

A minimum of 30 frames per sec. should be used for sampling TV video material with two display scans (fields) per sec., providing a minimum of 60 fields per sec. The lines of the second scan in the frame period should be interlaced with the lines of the first scan.

b. References: Requirements

1. MIL-HDBK-759A (1981): The frame rate for sampling video material should be a minimum of 30 per sec., except for slow-scan systems. Two display scans (fields) per frame period (a minimum of 60 per

sec.) should be used, with the lines of the second scan in the frame period interlaced with the lines of the first scan.

2. Woodson (1981): The TV signal should be interlaced 2:1, with 60 fields and 30 frames per sec.

2.2.3.1.6 Screen Size

a. IOS Design Recommendation

The width-to-height ratio for raster color picture monitors should be 4:3.

b. Reference

The design recommendation is from Woodson (1981).

2.2.3.1.7 TV Lens System

a. IOS Design Recommendation

A zoom lens used in TV systems can degrade performance up to 4% of the performance with a fixed-focal-length lens. Consequently, a good quality, fixed-focal-length lens should be used in the design of TV systems rather than a variable-focal-length lens.

b. Reference

Shurtleff (1980) identified this design requirement.

2.2.3.1.8 Direction of Scanning

a. IOS Design Recommendation

There are no scientific data to show that scanning orientations of raster lines other than horizontal are superior. Therefore, the horizontal orientation should be used.

b. Reference

This design recommendation was extracted from Shurtleff (1980).

2.2.3.1.9 TV Phosphors

a. IOS Design Requirement

Short- or medium-persistence, high-output phosphors should be used for TV screens; for example, P4 or P23 for black-and-white monitors, and P22 or P27 for color monitors.

b. Reference

This specification is contained in MIL-HDBK-759A (1981).

2.2.3.1.10 Distortion

a. IOS Design Requirement

Variations in spot diameter should not exceed a ratio of 1.5 to 1.0 at any two points on the TV screen. There should be no obvious nonlinearity anywhere on the screen for viewing alphanumeric formats or picture images.

b. Reference

MIL-HDBK-759A (1981) is the source of this design requirement.

2.2.3.2 Monochrome Large-Screen TV Projectors

Woodson (1981) provides a variety of design recommendations for monochrome large-screen TV projectors. These recommendations are identified below.

a. Picture Size: The width-to-height aspect ratio of the TV picture should be 4:3.

b. Resolution: For the specified brightness level, the limiting horizontal resolution should be at least 800 lines at the picture center and 700 lines at the corners. The vertical resolution should be at least 400 lines at the center and corners for monochrome video signals.

c. Luminance: The projector should provide luminance levels for the various image sizes as shown in Table 2-5.

Table 2-5. Image Size and Screen Luminance Requirements (From Human Factors Design Handbook (p. 543) by W.E. Woodson, 1981, New York, NY: McGraw-Hill, Inc. Copyright 1981 by McGraw-Hill, Inc. Reprinted by permission.)

Image size (ft.)	Screen luminance (fL)
6 x 8	62
9 x 12	28
12 x 16	16
15 x 20	10
24 x 32	4

d. Gray Scale Level: The viewer should be able to distinguish nine shades of gray and the white background.

e. Geometric Distortion: No point on the projected display should be displaced from its correct position by more than 1% of the picture height.

f. Trapezoidal Distortion: The projector should be able to correct for distortion resulting from the vertical tilt of the screen. The screen tilt from the perpendicular to the optical axis of the projector should be maintained within ±15°.

g. Interlace: The displacement of scan lines from the center position between lines of the alternate field should not be greater than 10% of the distance between the lines of the alternate field.

h. White Balance: A white corresponding to the Commission Internationale de l'Eclairage (CIE) illuminant "C" ($x = 0.310$, $y = 0.316$) should be able to be produced from a monochrome input signal by the TV monitor.

i. Scan Size: Controls for width and height should have sufficient range to vary raster size from -10% to +20% of the nominal dimensions.

2.2.3.3 TV Luminance

a. IOS Design Recommendation

Glare from ambient illumination on broadcast TV should be minimized. Light sources should not be located within 60° of the viewer's central visual field. The optimum luminance on the surface of the TV display is approximately 17 fL when measured from the central axis. The optimum measured at the largest angle of off-axis viewing is 13 fL. The maximum luminance for large-screen displays should not be more than 35 fL.

b. Reference

These guidelines were adapted from Woodson (1981).

2.3 Dot Matrix and Stroke Matrix (Segmented) Displays

2.3.1 General Requirements

The design criteria provided below are applicable to those displays (e.g., light-emitting diode, CRT, and gas discharge liquid crystal, and incandescent) used for presenting alphanumeric and symbolic information.

2.3.2 Dot Matrix Size

a. IOS Design Recommendation

The smallest dot mosaic that should be used for alphanumerics and symbols is 5 x 7, although a 7 x 9 matrix is preferred. The minimum matrix size is 8 x 11 when symbol rotation is required, but a 15 x 21 matrix is preferred.

b. References: Requirements

1. Elke et al. (1980): The smallest symbol definition for a dot mosaic should be 5 x 7. A display providing a 7 x 9 mosaic is preferred. If symbol rotation is required, the minimum definition is 8 x 11; but a 15 x 21 mosaic is preferred.

2. MIL-HDBK-759A (1981): A 5 x 7 dot matrix is the smallest that should be used for letters, numerals, or symbols. A 7 x 9 matrix is preferred when accuracy is important for display alphanumerics. If symbol rotation is required, the minimum matrix that should be used is 8 x 11; but a 15 x 21 matrix is preferred.

3. MIL-STD-1472C (1981): The smallest definition for a dot matrix should be 5 x 7, although a 7 x 9 matrix is preferred. A minimum dot matrix of 8 x 11 should be used when display symbol rotation is required; but a 15 x 21 matrix is preferred.

4. Shurtleff (1980): A 5 x 7 dot matrix should be used only when the quality of the display is good. The matrix should be 7 x 9 or larger if display degradation is expected and if detection accuracy is to be maintained at a level of 95% or greater.

5. Woodson (1981): A 5 x 7 dot mosaic is the minimum acceptable. A 7 x 9 mosaic is preferred.

2.3.3 Dot Size

a. IOS Design Recommendation

The optimum dot (emitter) size depends on the requirements of the viewer's task. For reading tasks, a 0.75-mm dot should be used; for search tasks, a 1.5-mm dot should be used. The dot should be between 1 and 1.2 mm when the display is used for both types of tasks.

b. Reference

These design recommendations are from Elke et al. (1980).

2.3.4 Dot Shape

a. IOS Design Recommendation

Display dots should be either circular or square. If the dots of a display are more elongated than circular, consideration should be given to providing a dot mosaic larger than 7 x 9 to aid symbol identification, such as a 7 x 11 or 9 x 11 dot mosaic.

b. References: Requirements

1. Elke et al. (1980): Either circular or square emitters should be used.

2. Shurtleff (1980): Dot elements for CRT displays should be as circular as possible. If the dots in a display are more elongated than circular, as with digital TV displays, a dot matrix larger than 7 x 9 should be considered to assist in symbol identification; perhaps a 7 x 11 or 9 x 11 dot mosaic.

2.3.5 Dot Spacing

a. IOS Design Recommendation

The space between dots should be minimized to provide the appearance of stroke continuity. The spacing-to-size ratio of dots should be 0.5 if possible.

b. References: Requirements

1. Elke et al. (1980): If possible, a dot spacing-to-size ratio of 0.5 should be used.

2. Shurtleff (1980): The spacing between dots should be minimized so that the symbol strokes will appear to be continuous.

2.3.6 Stroke Segments

a. IOS Design Recommendation

A seven-segment matrix should be used only for presenting numerics. Matrices providing 14, 16, or 23 segments are acceptable for the presentation of alphanumerics and are preferred to matrices having 17, 27, or 38 segments.

b. References: Requirements

1. Elke et al. (1980): For stroke mosaics, 16- and 23-segment fonts should be used in preference to fonts with 17, 27, or 38 segments.

2. MIL-HDBK-759A (1981): A seven-segment, bar-type matrix is acceptable for presenting numerals, but it cannot provide the full set of letters.

3. MIL-STD-1472C (1981): Fourteen- and 16-segment displays may be used for a variety of applications. Seven-segment displays should be used only for presenting numeric information.

4. Shurtleff (1980): Seven-segment displays are used for numerics, and 16-segment displays are used for alphanumeric displays.

5. Woodson (1981): Bar- , stroke- , and segment-patterned symbols are suitable only for numeric characters. The seven-segment format is the minimum acceptable configuration.

2.3.7 Character Size

a. IOS Design Recommendation

The minimum visual angle for dot and stroke matrix alphanumerics and symbols should not be less than 12 minutes of arc, although the preferred minimum is 16 minutes.

b. References: Requirements

1. Elke et al. (1980): The minimum visual angle for alphanumeric characters is 12 minutes of arc, and the preferred minimum is 16 minutes. A visual angle of at least 24 minutes of arc should be used for flight display alphanumerics.

2. MIL-HDBK-759A (1981): Alphanumeric characters should not be less than 12 minutes of arc and preferably not less than 16 minutes. Alphanumerics for flight displays should not subtend less than 24 minutes of arc.

3. MIL-STD-1472C (1981): The visual angle for alphanumeric and symbolic characters should not be less than 16 minutes of arc. Characters used in conjunction with flight displays should not subtend less than 24 minutes of arc.

2.3.8 Uppercase Alphanumerics

a. IOS Design Recommendation

Uppercase alphanumerics should be used.

b. References: Requirements

1. MIL-STD-1472C (1981): Alphanumerics should be uppercase.

2. Woodson (1981): Lowercase letters have been developed; but they are not recommended, because lowercase features are easily confused, especially when the viewer is required to read the display information rapidly.

2.3.9 Dot Color

a. IOS Design Recommendation

Dot colors for monochromatic matrix displays should be, in order of preference: (a) green (555 nm), (b) yellow (575 nm), (c) orange (585 nm), and (d) red (660 nm). Blue dots should be avoided.

b. References: Requirements

1. Elke et al. (1980): Same as MIL-STD-1472C (1981).

2. MIL-HDBK-759A (1981): Same as MIL-STD-1472C (1981).

3. MIL-STD-1472C (1981): The colors that should be used for monochromatic displays in order of preference are: (a) green (555 nm), (b) yellow (575 nm), (c) orange (585 nm), and (d) red (660 nm). Blue dots should not be used.

2.3.10 Viewing Angle

a. IOS Design Recommendation

The optimum angle between the display surface and the viewer's line of sight is 90° (i.e., perpendicular). An angle less than 45° should not be used.

b. References: Requirements

1. Elke et al. (1980): For viewing a display, the optimum horizontal angle is 90° straight on. The viewing angle should not be smaller than 45°, and under no circumstances should the viewing angle be less than 30°.

2. MIL-HDBK-759A (1981): The optimum viewing angle for a dot matrix display is perpendicular to the display. The user should not be required to view a dot matrix display at an angle larger than 45° off axis.

3. MIL-STD-1472C (1981): The optimum viewing angle is perpendicular to the display. The location of dot matrix displays should not require viewing at an angle larger than 35° off axis.

2.3.11 Luminance

a. IOS Design Recommendation

A display dimming control should be provided. The minimum display luminance should be 21 mL. The contrast ratio should be 8.5:1 or larger if possible.

b. References: Requirements

1. Elke et al. (1980): The minimum screen luminance should be 21 mL. If possible, the contrast ratio should be at least 8.5:1.

2. MIL-STD-1472C (1981): When applicable, dimming controls should be provided.

2.3.12 Character Spacing

a. IOS Design Recommendation

The spacing between characters should be 25% of the character dimension under low luminance levels (i.e., 1 fL). The spacing should approach 200% for maximum readability of a single character at high brightness levels. The between-character spacing within a word or number group should be 50% of the average character width in typical applications such as clear text messages and grouped numbers. Between words or groups, the spacing should be 75% to 100%. The spacing between character lines should not be less than 50% of the character height.

b. Reference

Woodson (1981) provides this design specification.

2.3.13 Font

2.3.13.1 Dot Matrix Font

a. IOS Design Recommendation

For a 7 x 9 dot mosaic, the fonts illustrated in Figures 2-3 and 2-5 might be best because the confusion between symbols is minimal. The commonly used Lincoln/MITRE fonts are shown in 5 x 7 dot mosaics in Figure 2-6 for comparative purposes.

b. References: Requirements

1. Shurtleff (1980): If a 5 x 7 dot matrix is to be used at all, the only recommendation that can be made based on the relevant experimental data is that the dot configuration for individual symbols should provide the appearance of continuous strokes and minimize the appearance of broken or disjointed symbol strokes. For a 7 x 9 dot mosaic, the best choice might be the Lincoln/MITRE font (Figure 2-3). If a full set of ASCII characters is required for presentation in a 7 x 9 dot matrix, the Lincoln/MITRE/Hazeltine character set (Figure 2-7) and the associated special symbols (Figure 2-8) are recommended based on research comparing symbols and their ability to minimize confusion.

2. Woodson (1981): The suggested character formation for a 7 x 9 dot mosaic is shown in Figure 2-5. The character set was designed to minimize recognition errors, or at least the possible confusion between characters.

2.3.13.2 Stroke Matrix Font

a. IOS Design Recommendation

An italic or sloping stroke mosaic may be used, but the slope should not be greater than 11° from vertical.

b. References: Requirements

1. MIL-HDBK-759A (1981): An italic or sloping matrix may be used, but the slope should not exceed 11°.

2. Woodson (1981): Stroke mosaic characters may be slanted, but the slope should not exceed 5° to 7° or legibility will suffer.

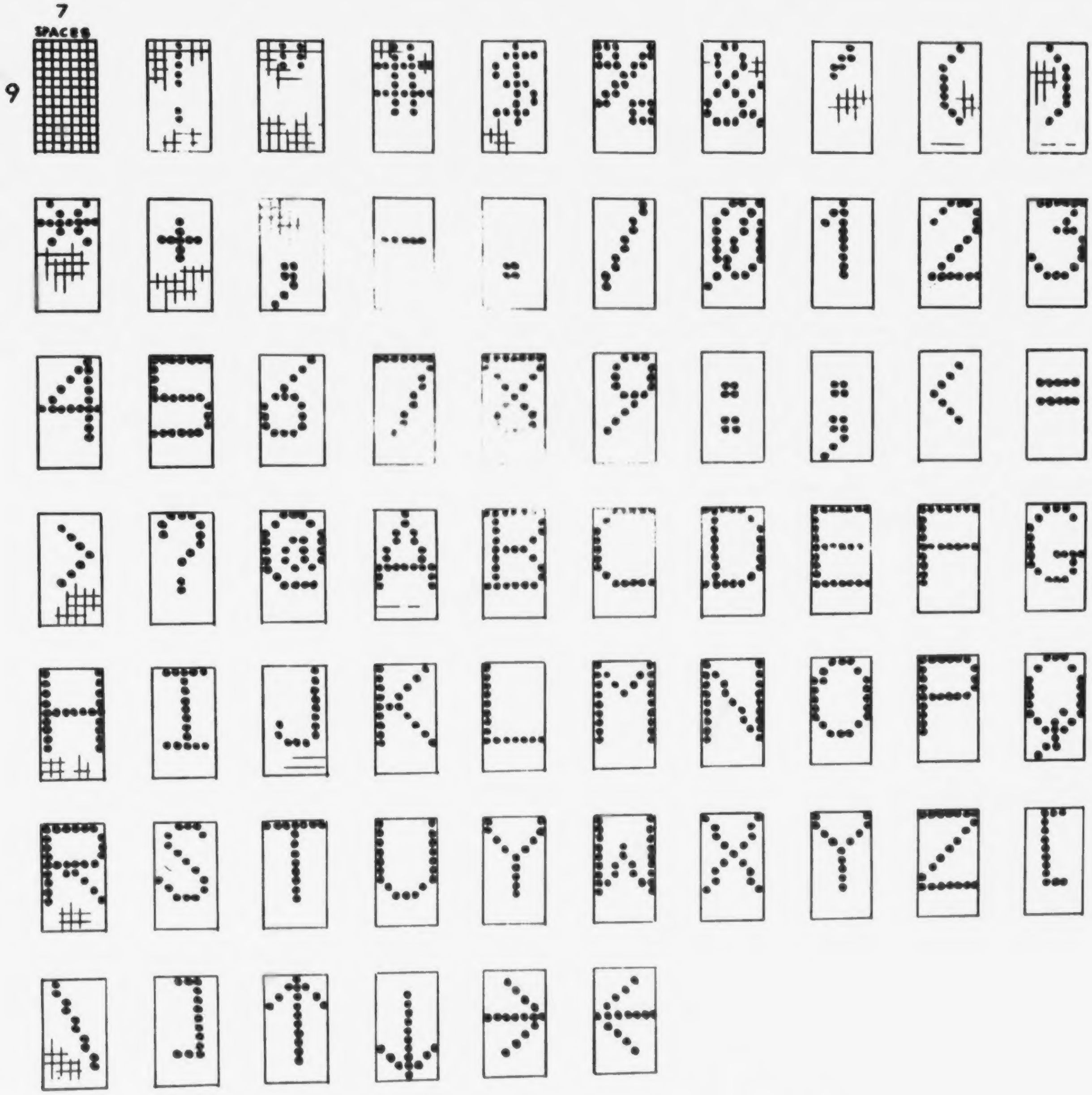


Figure 2-5. Character Font for a 7 x 9 Dot Matrix.
(From Human Factors Design Handbook [p. 545] by
W. E. Woodson, 1981, New York, NY: McGraw-Hill,
Copyright 1981 by McGraw-Hill, Inc. Reprinted
by permission.)

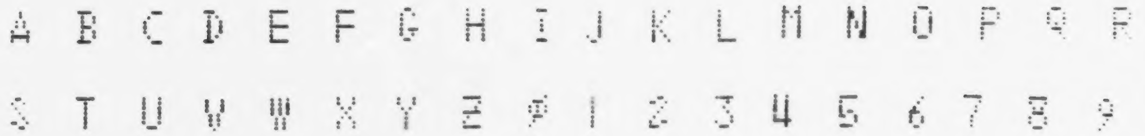

A B C D E F G H I J K L M N O P Q R
S T U V W X Y Z Ø 1 2 3 4 5 6 7 8 9

Figure 2-6. Lincoln/MITRE Font for a 5 x 7 Dot Matrix. (From Shurtleff, 1980.)

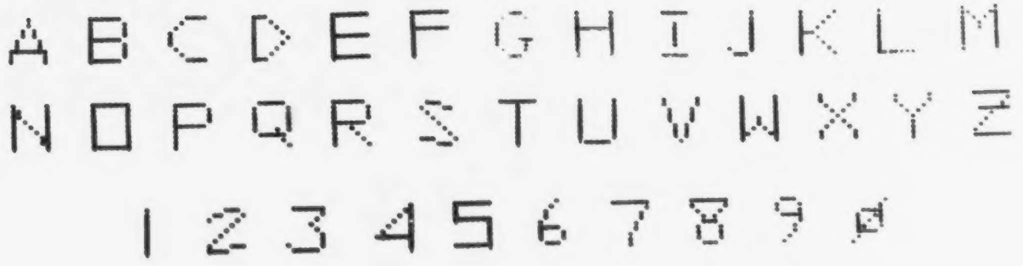

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 Ø

Figure 2-7. Lincoln/MITRE/Hazeltine Font for a 7 X 9 Dot Matrix. (From Shurtleff, 1980.)

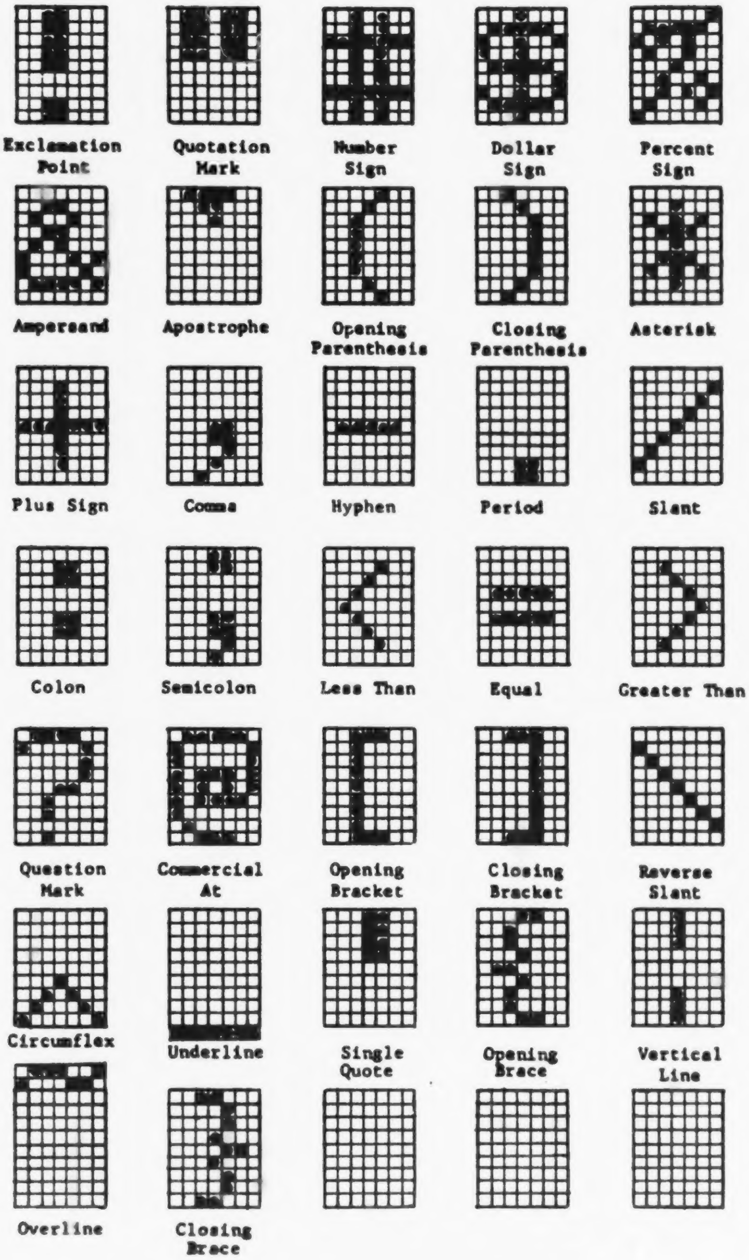

Exclamation Point
Quotation Mark
Number Sign
Dollar Sign
Percent Sign
Ampersand
Apostrophe
Opening Parenthesis
Closing Parenthesis
Asterisk
Plus Sign
Comma
Hyphen
Period
Slant
Colon
Semicolon
Less Than
Equal
Greater Than
Question Mark
Commercial At
Opening Bracket
Closing Bracket
Reverse Slant
Circumflex
Underline
Single Quote
Opening Brace
Vertical Line
Overline
Closing Brace

Figure 2-8. Graphic Symbols for Use with the Lincoln/MITRE/Hazeltine Font in a 7 x 9 Dot Matrix. (From Shurtleff, 1980.)

2.3.14 Dot Matrix vs. Stroke Matrix Utilization

a. IOS Design Recommendation

Either dot-generated or stroke-generated displays may be used, although dot matrix patterns are more readable because curved portions of individual display signals can be produced with dot mosaics. Under conditions of severe display degradation, stroke mosaics might provide better identification accuracy.

b. References: Requirements

1. MIL-HDBK-759A (1981): Dot matrix patterns are more readable than segmented displays.

2. Shurtleff (1980): For general display applications, symbols produced from either dots or strokes may be used. If degraded display conditions are anticipated, such as symbol overprinting or small visual size, stroke matrix symbols might be considered in preference to dot matrix symbols because identification accuracy is better for stroke-generated symbols than dot-generated symbols under these conditions.

3. Woodson (1981): The readability of dot mosaics is superior to that for segmented mosaics because of the dot mosaics' capability to produce curved portions of characters.

3. MANUAL CONTROLS

3.1 Introduction

The IOS controls permit the instructor to direct and manage the training process. For example, they are used to start up the trainer subsystems, to select the training environment, to set up the training conditions, to insert the appropriate training stimuli, to activate the advanced instructional features, to initiate the student data recording systems, and to operate the IOS/trainer communications system. The controls provided for these functions should be designed in accordance with the human factors standards to ensure maximum operator performance efficiency. This section on manual controls contains standardized design guidelines for the types of controls commonly used in flight simulator IOSs. They are (a) pushbuttons, (b) legend switches, (c) keyboards, (d) keysets, (e) menu selectors, (f) toggle switches, and (g) rocker switches.

3.2 General Requirements

a. IOS Design Recommendation

The selection, design, and use of IOS controls should be consistent with standard human factors requirements, as follows:

1. Feedback: The controls should provide feedback so that the user knows they have been activated, and when the results of the input are

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not instantaneous, visual feedback should be provided to show that the system is processing the control input.

2. Resistance: The controls should have enough resistance to dampen spurious user inputs, but excessive force should not be required to operate the controls. If excessive force is required, the user may become physically fatigued and also encounter difficulty in maintaining an efficient operating position.

3. Location: The location of controls should not require the user to use an uncomfortable posture or to make frequent long-reaching movements. Furthermore, all controls used in a control series or sequence should be within the user's reach at a given position.

4. Size and Shape: The size and shape of the controls used should be predicated on the size of the controlling member (i.e., finger, hand, or foot). Size adjustments should be made as appropriate to accommodate the use of gloves, mittens, and shoes. Control shape should be compatible with the type of handling or motion required to operate the control.

5. Inadvertent Activation: Adequate separation should be provided between controls to prevent the inadvertent activation of adjacent controls.

6. Control Surface: The surface of the controls, such as flat or concave and smooth or rough, should be compatible with the required control operation.

b. Reference

The general requirements for manual controls were adapted from Woodson (1981).

3.3 Pushbuttons (Finger- or Hand-Operated)

3.3.1 Applications

a. IOS Design Recommendation

Pushbutton switches should be used primarily for the following applications: (a) simple switching between two conditions, (b) selection of alternative ON-OFF functions from an array of related conditions or subsystem functions, (c) release of a locking system, or (d) entry of a discrete control order. Pushbuttons should not be used merely to provide a uniform control panel appearance, or where another type of control could be used to conserve panel space. Pushbutton controls may be used singly or in combination for any of the following control operations (see also Table 3-1 for representative pushbutton applications):

1. Momentary Contact: A momentary-contact operation involves a "push and hold" action for ON and a "release" action for OFF; that is, the control function is active only as long as the pushbutton is depressed.

Table 3-1. Representative Pushbutton Switch Applications
(From MIL-HDBK-759A, 1981.)

Function	Switch action	Switch config.	Switch State Feedback Options					
			Depressed switchcap	Integral lamp(s)	Integral legend(s)	Adjacent lamp(s)	Adjacent legend(s)	Other display reflecting switch action
Send short discrete signal to initiate or terminate some other function.	Momentary contact	Single button	Momentary only	Momentary only	Momentary only	Momentary only	Momentary only	Sufficient
Send short signal of controllable duration.	Momentary contact	Single button	Momentary only	Momentary only	Momentary only	Momentary only	Momentary only	Sufficient
Choose between two mutually exclusive states	Alternate action, latching	Two-button interlocked or	If mechanically latched	C	Sufficient	C	Sufficient	C
		Single-button	If mechanically latched	C	Sufficient	C	Sufficient	C
Step through three or more switch states	Stepping, latching	Single button with legend matrix	(No)	(No)	Sufficient (if multiple legend)	C	Sufficient	C
Independently choose one out of three or more mutually exclusive states	Latching and interlocked	Array of buttons	If mechanically latched	C	Sufficient	C	Sufficient	C
Independently choose two or more out of a set of control functions each having two states	Alternate action, latching	Array of buttons	If mechanically latched	C	Sufficient	C	Sufficient	C

Notes:
1. The feedback referred to pertains only to knowledge of switch state, not system state (which may impose additional feedback requirements).
2. A feedback option designated "sufficient" means that, properly instrumented, it can provide all the information the operator needs concerning switch state; other methods showing annotation or C (contributing) need to be used in combination to provide adequate feedback.

The pushbutton for this operation may be any one of the following: (a) nonilluminated, (b) continuously illuminated switchcap light or legend, or (c) illuminated switchcap light when the switch is in the ON position.

2. Alternate Action: For a single function, an alternate-action operation may be implemented using either two buttons or a single button. With the single-button operation, the button is first depressed for ON and then depressed a second time for OFF. Feedback should be provided when the switch is ON by the use of either a switchcap light or legend, or by an adjacent light or legend. With the two-button operation, the buttons are interlocked such that one button is depressed and the other is in the up position. When the button in the up position is depressed, the other button goes up. The depressed button provides feedback on switch state, but additional feedback should normally be provided through the use of a switchcap light or an adjacent light or legend.

3. Stepping Action: With stepping-action pushbuttons, successive pushes of the button cycle it through three or more states. Feedback of the switch state may be provided by selectively illuminating integral or adjacent legends.

4. Combined Actions: Sets of related switch operations may be combined as an assembly. They may be independent, interlocked, or a combination of both; they may be momentary, latching, or a combination of both; and they may be nonilluminated or have switchcap lights or legends. Feedback of the active switch state should always be provided. Interlocking and latching actions may be either mechanical or electrical.

b. Reference

These guidelines for pushbutton applications are from MIL-HDBK-759A (1981).

3.3.2 Shape

a. IOS Design Recommendation

Switchcap surfaces should generally be flat with rounded edges; but the cap surfaces may be concave to provide proper finger centering, or they may be designed to provide high frictional resistance to prevent slipping. Cap shapes may be round, square, or rectangular as long as they do not compromise the identification or legend requirements and as long as the finger, thumb, or hand contact area is adequate. Square and rectangular pushbuttons provide more area for labels or legends, and a rectangular button oriented horizontally provides more label or legend space than a vertically oriented button. Shape can also be used as a cue where there are other controls and indicators present.

b. References: Requirements

1. MIL-HDBK-759A (1981): In general, switchcap surfaces should be flat; and the edges should be rounded. However, the cap surfaces may be concave to ensure proper finger centering. General cap shapes may be round, square, or rectangular as long as they are compatible with the identification or legend requirements and the finger, thumb, or hand contact area is adequate.

2. MIL-STD-1472C (1981): The surface of pushbuttons should normally be concave (indented) to fit the user's finger. If this is not practical, the surface should provide high frictional resistance to prevent slipping.

3. Woodson (1981): Square and rectangular pushbuttons provide more area for labeling. Shape can also serve as a cue for determining differences among control functions. For example, a round shape is seldom mistaken for an advisory indicator when pushbuttons are used in combination with advisory indicators.

3.3.3 Dimensions, Displacement, Resistance, and Separation

a. IOS Design Recommendation

The dimensions, displacement, and separation of finger- or hand-operated pushbuttons should conform to the criteria in Table 3-2. These criteria should not be used for keyboard pushbuttons, however. The actuating force for pushbuttons should be within the following limits:

1. Keypad and keyset pushbuttons: 0.25 N to 1.5 N.
2. Other single-finger-actuated pushbuttons: 0.25 N to 11.1 N.
3. Large (25-mm square or larger) panel-mounted pushbuttons for thumb actuation: 1.1 N to 16.7 N.
4. Larger (minimum 38-mm wide) panel-mounted pushbuttons for multi-finger or heel-of-hand actuation: 1.7 N to 22.2 N.

b. References: Requirements

1. MIL-HDBK-759A (1981): The dimensions, displacement, and separation of finger- or hand-operated pushbuttons should conform to the criteria provided in Table 3-2. These criteria, however, are not applicable to keyboard pushbuttons. The actuating force for pushbuttons should be in the following ranges:

(a) Keypad and keyset pushbuttons: 0.25 N to 1.5 N.

(b) Other single-finger-actuated pushbuttons: 0.25 N to 11.1 N.

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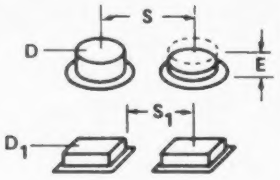
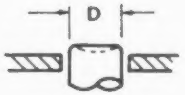
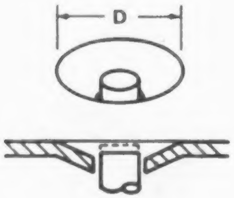
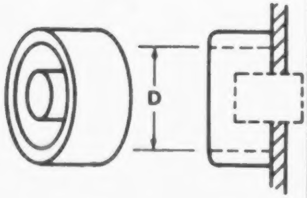
Table 3-2. Pushbutton Switch Design Criteria (From MIL-HDBK-759A, 1981.)

	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	**PANEL-MOUNTED PUSH BUTTONS:** SINGLE FINGER, ONE BUTTON AT A TIME. NON-LEGEND OR BUTTONS THAT REQUIRE ONLY A SINGLE NUMBER ON THE FRONT SURFACE MAY BE ROUND, SQUARE OR RECTANGULAR.	D - MIN DIAM, OR DIMENSION (D_1) = 10mm*	—	—	E - EXCURSION, PREFERRED MIN = 3.2mm PREFERRED MAX = 6.5mm ADD FOR GLOVED OP'N 13mm NOTES: (1) THE DEPRESSED BUTTON (E_1) SHALL REMAIN EXPOSED BY AT LEAST 2.5mm (2) SWITCHES WITH NO MOTION (E.G.,) THERMAL) ARE PERMISSIBLE SUBJECT TO THE APPROVAL BY THE PROCURING ACTIVITY	S - MIN = 19mm (OR) S_1 - MIN = 13mm S = 25mm WITH GLOVES
	A CONCAVE SURFACE MAY BE USED TO AID FINGER-CENTERING (NON-GLOVE OP'N ONLY).	MAX = 19mm D - MIN = 13mm	—	—		
	RECESSED BUTTON TO MINIMIZE INADVERT END OPERATION. TAPERED "WELL" GUIDES FINGER.	—	D - MIN WELL OPENING = 19mm; 32mm WITH GLOVES.	—		
	PREVENT INADVERTENT OPERATION OF CRITICAL SWITCH, EITHER WITH GUARD RING, OR PANEL WELL.	—	D - SAME AS ABOVE	—		

*FOR MINIATURIZED APPLICATIONS DIAMETER AS SMALL AS 3.2mm MAY BE USED SUBJECT TO APPROVAL BY THE PROCURING ACTIVITY.

Table 3-2. Pushbutton Switch Design Criteria (cont'd)

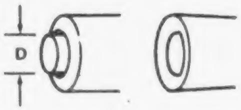
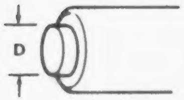
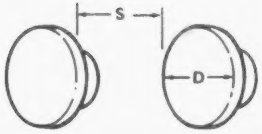
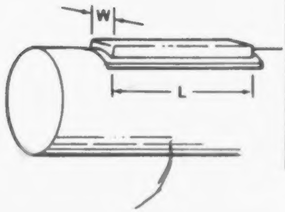
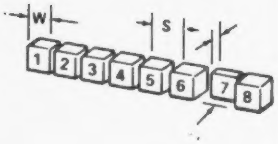
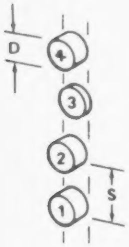
	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	**HANDLE, END-MOUNTED, PUSH BUTTON SWITCH:** **INDEX FINGER-OPERATED. RECESS TO PRECLUDE INADVERTENT OPERATION.**	D - MINIMUM DIAM = 10mm	–	–	SAME AS ABOVE	N/A
	**THUMB-OPERATED**	D - MINIMUM = 13mm	–	–	SAME AS ABOVE	N/A
	**ALTERNATE FINGER OR HEEL OF THE HAND OPERATION. CONVEX SURFACE DESIRABLE.**	D - MIN = 25mm	–	–	SAME AS ABOVE	S - MIN FOR PALM OPN = 75mm
	**GRIP HANDLE SWITCH** **ALTERNATE MULTI-FINGER OR PALM OPERATION**	W - MIN = 6.5mm	L - PREFERRED MIN = 25mm	–	SAME AS ABOVE	N/A

Table 3-2. Pushbutton Switch Design Criteria (concluded)

	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
 	GANGED PUSH BUTTON ASSEMBLY: SQUARE, RECTANGULAR OR ROUND SHAPES ARE ACCEPTABLE. DEPRESSION OF ANY BUTTON SHALL CAUSE ANY PREVIOUSLY-DEPRESSED BUTTON TO RETURN TO DEACTIVATED POSITION. NUMBERED BUTTONS SHALL PROGRESS AS ILLUSTRATED.	W OR D MIN = 10mm (13mm FOR GLOVES)	–	–	X a - MIN EXPOSURE WHEN DEPRESSED = 3.2mm X b - MIN DEPRESSION TO ACTIVATE = 3.2mm (PREFERRED = 5mm) NOTE: MAX DISPLACEMENT SHALL NOT EXCEED 13mm	S - CTR-CTR SPACING MIN = 19mm (25mm FOR GLOVES)

(c) Large (2.5-mm square or larger) panel-mounted pushbuttons for thumb actuation: 1.1 N to 16.7 N.

(d) Larger (minimum 38-mm wide) panel-mounted pushbuttons for multi-finger or heel-of-hand actuation: 1.7 N to 22.2 N.

2. MIL-STD-1472C (1981): The dimensions, resistance, displacement, and separation between adjacent edges of finger- or hand-operated pushbuttons should conform to the criteria in Table 3-3. However, these criteria do not apply to pushbuttons for keyboards.

3. Woodson (1981): The criteria contained in Table 3-4 should be used for finger-operated pushbuttons. The actuating force for pushbuttons should be in the range of 10 to 20 oz (283 to 567 g), although as high as 40 oz (1134 g) is acceptable.

3.3.4 Feedback

a. IOS Design Recommendation

Positive feedback should be provided to inform the user that the pushbutton has been activated or deactivated. One or more of the following forms of feedback should be implemented when appropriate:

1. Visible pushbutton displacement.
2. Snap-action control.
3. Audible "click."
4. Illuminated switchcap or legend.

Snap-action control should not be too heavy if frequent and long-term use is anticipated.

b. References: Requirements

1. MIL-HDBK-759A (1981): To indicate that the pushbutton switch has been activated or deactivated, positive feedback should be provided. The following forms of feedback should be considered:

(a) Visible pushbutton displacement.

(b) Tactile/auditory indication; that is, a gradual buildup of resistance to a sudden release of resistance (snap-action control) with an audible click.

(c) An accompanying visual indication, such as an illuminated switchcap.

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Table 3-3. Pushbuttons for Finger or Hand Operation (From MIL-STD-1472C, 1981.)

	Dimensions (Diameter - D)		Resistance		
	Fingertip	Thumb or Palm	Single Finger	Different Fingers	Thumb or Palm
Mininum	9.5 mm	19 mm	2.8 N	1.4 N	2.8 N
Maximum	25 mm	-	11 N	5.6 N	23 N

	Displacement (A)	
	Fingertip	Thumb or Palm
Minimum	2 mm	3 mm
Maximum	6 mm	38 mm

	Separation (S)			
	Single Finger	Single Finger Sequential	Different Fingers	Thumb or Palm
Minimum	13 mm	6 mm	6 mm	25 mm
Preferred	50 mm	13 mm	13 mm	150 mm

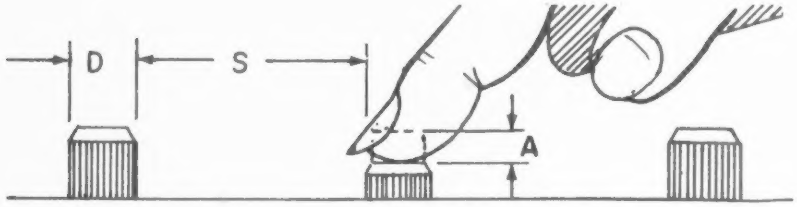
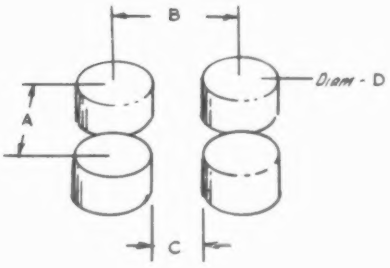
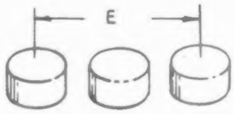


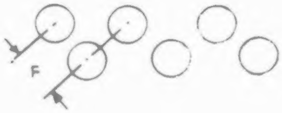
Table 3-4. Design Guidelines for Pushbuttons
(From Human Factors Design Handbook [p. 609]
by W.E. Woodson, 1981, New York, NY:
McGraw-Hill, Inc. Copyright 1981
by McGraw-Hill, Inc. Reprinted by permission.)

Pushbutton arrangement	Minimum pushbutton separation					
	A	B	C	D	E	F
Vertical Plane						
No Gloves	1.9 cm	1.6 cm	0.476 cm	0.64 cm	3.17 cm	1.9 cm
With Gloves	9.45 cm	4.12 cm	0.95 cm	3.17 cm	5.72 cm	4.45 cm
Horizontal Plane						
No Gloves	2.54 cm	2.22 cm	1.11 cm	1.27 cm	3.81 cm	2.54 cm
With Gloves	5.1 cm	4.76 cm	0.95 cm	3.17 cm	5.72 cm	5.1 cm
Under Severe Vibration or Oscillation	7.6 cm	-	-	7.6 cm	-	-
For Blind Selection	15 cm apart in front of operator; 31 cm apart when buttons are located in the peripheral areas.					

Note: Guidelines apply to any shape of button.







2. MIL-STD-1472C (1981): A positive indication of control activation should be provided, such as snap feel, audible click, or integral light.

3. Woodson (1981): Positive pushbutton actions should be used; that is, resistance should begin slowly and build rapidly, with a final sudden drop to indicate switch activation. An audible snap action is recommended under high ambient noise conditions, but the snap action should not be too heavy if the switch is to be operated frequently for long periods of time.

3.3.5 Labels

a. IOS Design Recommendation

Panel labels and/or symbols may be used to identify pushbuttons, but labels placed on the pushbutton face are preferred when size and other use factors are compatible. The criteria for labels, symbols, and legends should be used. Normally, labels should be readable with or without internal illumination; but they need not be visible during an operating mode in which the button is not used. A lamp test capability and/or dual lamp reliability should be provided, except for switches using light-emitting diodes instead of incandescent lamps. In addition, no more than three lines of lettering should normally be used on a legend plate. Incandescent lamps in legend switches should be replaceable manually from the front of the panel, and the legend or cover should be keyed to prevent the possibility of interchanging legend covers.

b. Reference

These design recommendations are from MIL-HDBK-759A (1981).

3.3.6 Inadvertent Switch Activation

a. IOS Design Recommendation

Inadvertent switch activation can be minimized through the application of the appropriate criteria in Table 3-2. If it is imperative, however, to prevent the accidental activation of a switch, a switch guard should be provided that requires a special action on the part of the operator for the switch to be activated.

b. References: Requirements

1. MIL-HDBK-759A (1981): The criteria provided in Table 3-2 are the primary methods for minimizing inadvertent switch activations. However, if it is imperative to prevent accidental activation of a specific switch, a channel or cover guard should be provided or any other suitable alternative that requires the operator to perform an action before the switch is finally activated.

2. MIL-STD-1472C (1981): When it is imperative to prevent the accidental activation of the controls, a channel or cover guard should be used. The switch guard should not interfere with the operation of the protected control or adjacent controls.

3. Woodson (1981): To preclude inadvertent activation, the pushbutton should be recessed below the adjacent panel wall. The "well" should be at least 2.5 cm in diameter for bare-hand operation and at least 5.1 cm for gloved-hand use. The sides of the well may be tapered to aid the operator in locating the button. When inadvertent switch activation could be serious, consideration should be given to the use of accentuated button guards. Rail-type guards that separate buttons are effective because the height of the guard prevents the operator's finger from slipping over to the adjacent switches and because they allow switch labels to be seen with minimum interference.

3.4 Legend Switches

3.4.1 Applications

a. IOS Design Recommendation

Both MIL-HDBK-759A (1981) and MIL-STD-1472C (1981) provide design guidelines for legend switches, which are specialized pushbuttons bearing legends on the switch cap.

Legend switches are particularly well suited to the following applications:

1. To display qualitative information about an important system condition that requires the operator's attention.

2. To reduce the demands on the operator to interpret information.

3. To identify a functional grouping or a matrix of control switches and indicators when space is very limited.

b. Reference

These guidelines for the application of legend switches are from MIL-HDBK-759A (1981).

3.4.2 General Requirements

a. IOS Design Recommendation

The following requirements apply to legend switches:

1. They should be located within a 30° cone along the operator's normal line of sight.

2. They should provide a detent or audible click as an indication that the switch has been actuated.

3. Switch lamps should be replaceable from the front of the panel.

4. Legends should be readable with or without internal illumination.

5. A lamp test capability should be provided unless the switches have duplicate bulbs, dual filaments, or equivalent reliability.

b. Reference

These requirements for legend switches are contained in MIL-HDBK-759A (1981).

3.4.3 Dimensions, Displacement, Resistance, and Separation

a. IOS Design Recommendation

The minimum and maximum dimensions, displacement, resistance, and separation between adjacent legend switches should conform to the criteria presented in Table 3-5. Barriers are required on critical switches and switches that could be activated inadvertently. The barriers should not interfere with the readability of the labels.

b. References: Requirements

1. MIL-HDBK-759A (1981): The minimum and maximum dimensions, displacement, resistance, and separation for legend switches are provided in Table 3-5.

2. MIL-STD-1472C (1981): The dimensions, resistance, displacement, and separation between adjacent edges of legend switches should conform to the criteria provided in Table 3-5. Barriers are required on critical switches and switches that could be activated inadvertently. Barriers should not interfere with the readability of controls, labels, or displays.

3.5 Keyboards, Keysets, and Menu Selectors

3.5.1 Applications

a. IOS Design Recommendation

Guidelines for the proper use of keyboards, keysets, and menu selectors are provided below.

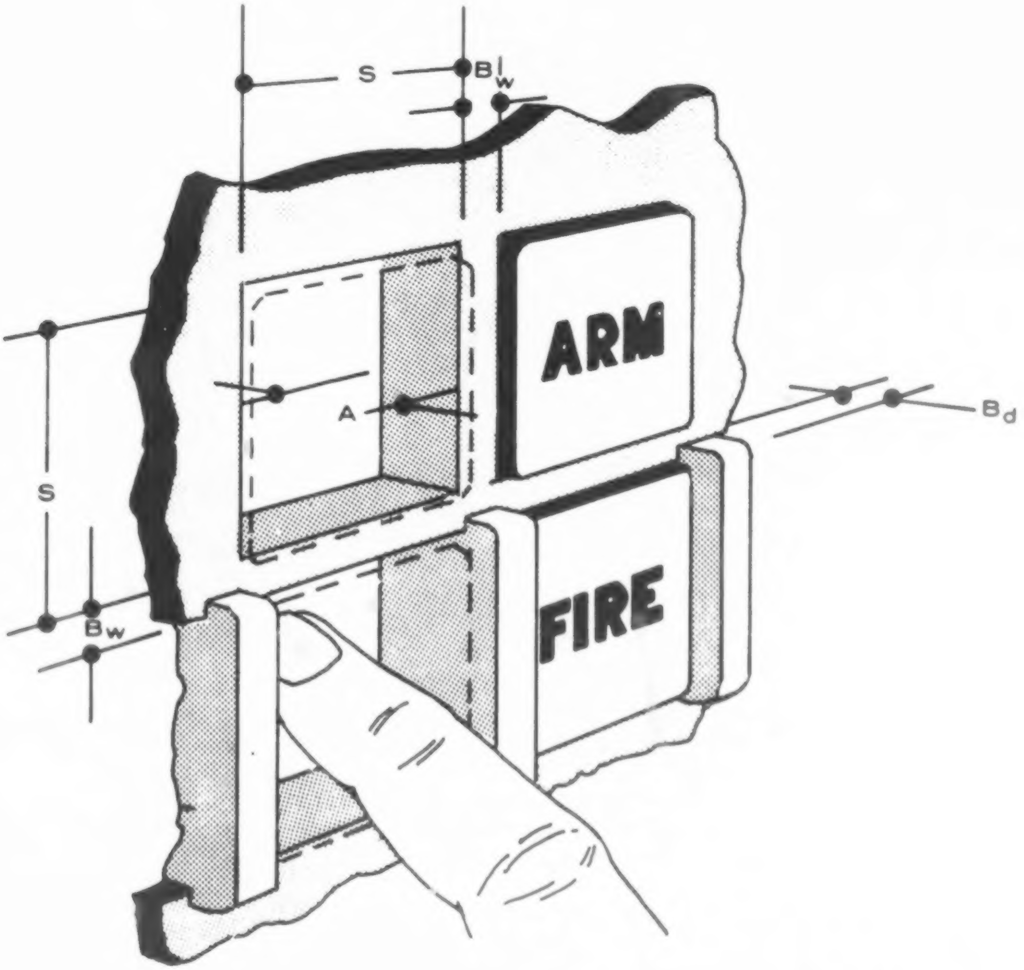
1. Numeric Keyboards: Where frequent entry of numerics is required, numeric keyboards should be used.

2. Alphanumeric Keyboards: When both alphabetic text and numerical data are to be entered that could not otherwise be accomplished with smaller keysets having dedicated or programmable keys or with menu selection techniques, alphanumeric keyboards with standard typewriter key configurations should be used.

Table 3-5. Legend Switch Design Criteria (From MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

	Size (S)	Displacement (A)	Barriers[a] (Bw)	 (Bd)	Resistance	Data source
Minimum	19 mm	3 mm[b]	3 mm	5 mm	280 mN	MIL-HDBK-759A, 1981
	19 mm[c]	3 mm	3 mm	5 mm	2.8 N	MIL-STD-1472C, 1981
Maximum	38 mm	6 mm	6 mm	5 mm	11 N	MIL-HDBK-759A, 1981
	38 mm	6 mm	6 mm	5 mm	16.7 N	MIL-STD-1472C, 1981

[a] Barriers will have rounded edges.
[b] 5 mm for positive switches.
[c] 15 mm where switch is not depressed below the panel.



3. Keysets: When the number of switching functions is minimal and need not change with time or operational condition, keysets should be used, with each key dedicated to a specific switching function. However, when switching requirements vary substantially for different phases or modes of operation and the total number of switching functions cannot be conveniently managed with dedicated keys, multifunction (programmable) keysets should be used.

4. Menu Selectors: The display and selection of switchable states on a CRT may be accomplished with menu selection techniques as an alternative to the multifunction keyset.

b. Reference

The guidelines for the application of keyboards, keysets, and menu selectors were adapted from MIL-HDBK-759A (1981).

3.5.2 Keyboards

3.5.2.1 Numeric Keyboards

3.5.2.1.1 Configuration

a. IOS Design Recommendation

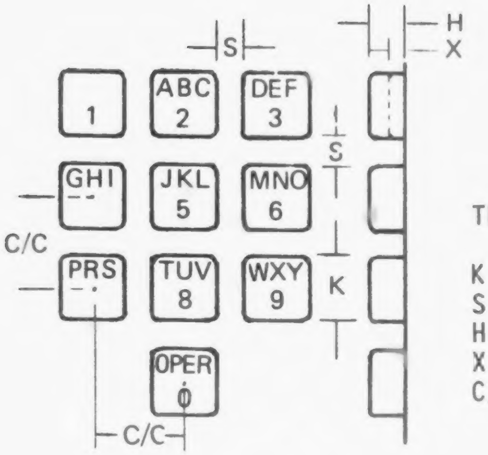
A keyboard used for numeric data entry, telephone, and communication functions should be configured in a 3 x 3 + 1 matrix, with the digits 1, 2, and 3 from left to right on the top row and the zero digit centered on the bottom row as illustrated in Figure 3-1.

b. References: Requirements

1. Cakir, Hart, and Stewart (1980): In most applications, the layout of keys on telephone and adding machine keypads in a 3 x 3 + 1 matrix is more efficient than a linear numeric key arrangement as used in the standard typewriter configuration. Additionally, research indicates that the telephone layout, which is read from left to right and top to bottom, is preferable to the adding machine layout, which is read from left to right and bottom to top, especially for low-skill operators. Therefore, it is desirable to use a numeric keyboard layout compatible with the telephone keypad.

2. Elke et al. (1980): The configuration of a keyboard that is used to enter only numeric information should be a 3 x 3 + 1 matrix, with the digits 1, 2, and 3 placed left to right across the top row of keys and the zero digit centered on the bottom row as used on telephone keypads.

3. MIL-HDBK-759A (1981): The pushbutton-telephone-keypad configuration (Figure 3-1) should be used for telephones, communications addressing functions, or entry of numeric data. This configuration is a 3 x 3 + 1 matrix, with the top row, from left to right, consisting of the numerals 1, 2, and 3; the second row, 4, 5, and 6; the third row, 7, 8, and 9; and zero centered on the bottom row.



TELEPHONE:

K - Key Size = 0.95 cm
S - Separation = 0.6 cm
H - Height = 0.6 cm
X - Depressed Extension = 0.16 cm
C/C - Center/Center Spacing = 1.67 cm

Figure 3-1. Recommended Keyboard Configuration for Telephone Use and Numeric Data Entry. (From MIL-HDBK-759A, 1981.)

4. MIL-STD-1472C (1981): A keyboard used solely to enter numeric information should be configured in a 3 x 3 + 1 matrix, with the zero digit centered on the bottom row.

5. Woodson (1981): Communications (telephone) keyboards and data entry (calculator) keypads provide two standardized approaches to the arrangement of keys. Communications keyboards with a 3 x 3 + 1 matrix are laid out in conformity to the results of research on key arrangement where 1 is on the top row and left side, and the keys are read from the top to the bottom and from left to right. Data entry keypads, however, which are arranged in a 3 x 3 + 1 matrix, have become standardized because of frequency of use, but are not in conformity with the key arrangement research. Data entry keypad layouts are based on a principle of reading from the bottom and to the right, with values increasing from left to right and from bottom to top. It is not recommended that the data entry keypad arrangement be changed, but the following discrepancies should be noted, as they may have implications for future keyboard designs:

(a) Although the numerals are read from bottom to top, zero--the last digit normally entered--is at the bottom.

(b) The data entry key arrangement requires added initial search time because individuals are accustomed to reading from the top down.

3.5.2.1.2 Dimensions, Resistance, Displacement, and Separation

a. IOS Design Recommendation

The criteria in Table 3-6 are recommended for use in numeric keyboard design, except that the actuating force (resistance) should be in the range of 0.25 N to 3.9 N. If the user is expected to wear gloves or mittens or be exposed to above-normal vibration or acceleration, the larger actuating forces should be used. Pushbuttons for telephone-type keyboards should be concave, if possible, to aid the users in centering their fingers on the buttons. If touch-activated keys are used, key displacement may be less than that recommended in the table. The actuating force range is not applicable to touch-actuated switches.

b. References: Requirements

1. MIL-HDBK-759A (1981): Commercially available telephone-type keypads may be used unless otherwise specified. The minimum dimensions, displacement, and separation of other keypads should be consistent with the design of commercial pushbutton phones except for the following:

(a) If touch-activated switches are used with appropriate feedback, key displacement may be as little as zero.

(b) If heavy gloves or mittens are to be worn by the user, key size, separation, and displacement should conform to the criteria in the Table 3-6.

(c) The actuating force required for keypads should be in the range of 0.25 to 3.9 N. (This force range is not applicable to touch-activated keypads.) Whenever the user is expected to wear gloves or mittens or will be exposed to substantial vibration or acceleration, the larger actuating forces should be used.

2. MIL-STD-1472C (1981): The control dimensions, resistance, displacement, and separation between adjacent edges of the keys that comprise the keyboard should conform to the specifications provided in Table 3-6.

3. Woodson (1981): The pushbuttons for telephone keyboards should be concave, to aid the users in centering their fingers on the buttons. The design of keyboards should be consistent with the following criteria:

(a) The buttons should be 17 mm square.

(b) The distance between the centers of adjacent buttons should be 17 mm.

(c) The separation between buttons should be 6 mm.

Table 3-6. Keyboard Design Criteria (From MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

	Dimensions (Diameter)		Resistance		
	Bare hand	Heavy mittens	Numeric	Alpha-numeric	Dual function
Minimum	10 mm	19 mm	1 N	250 mN	250 mN
Maximum	19 mm	-	4 N	1.5 N	1.5 N
Preferred	13 mm	19 mm	-	-	-

	Displacement			
	Numeric	Alpha-numeric	Dual function	Separation (between adjacent keys)
Minimum	0.8 mm	1.3 mm	0.8 mm	6.4 mm
Maximum	4.8 mm	6.3 mm	4.8 mm	-
Preferred	-	-	-	6.4 mm

3.5.2.1.3 Slope and Mounting

a. IOS Design Recommendation

Keyboard pushbuttons should slope upward toward the back at an angle of between 10° and 30° from the horizontal. The preferred slope is 17° to 18°. A keyboard may be mounted wherever it is most convenient to use. When frequent use is required, keyboards should be mounted in the preferred location for controls, as described in Section 4.

b. References: Requirements

1. MIL-HDBK-759A (1981): The keys should slope upward toward the back at an angle of between 10° and 30° from the horizontal. A 17° slope is preferred. Keypads may be mounted where they are most convenient to use. When keypads require frequent use, they should be mounted in the preferred location for controls.

2. MIL-STD-1472C (1981): Nonportable keyboards should be sloped 15° to 25° from the horizontal, and the preferred slope is 17° to 18°. The slope of a portable device may be varied according to the user's preference.

3. Woodson (1981): A telephone keyboard should slope toward the back, up to an angle of 30° from the horizontal.

3.5.2.1.4 Feedback

a. IOS Design Recommendation

Feedback should be provided to inform the operator that (a) the key that was pressed was, in fact, actuated; (b) the intended key selection was the one that was actually selected; and (c) the code, data, and so forth that were entered are complete and ready for the next operation.

b. References: Requirements

1. MIL-HDBK-759A (1981): Feedback should be provided to inform the operator whether (a) the key that was pressed was, in fact, actuated; (b) the intended key selection was the one that was actually selected; and (c) an entire message or message segment is ready for the next operation, such as filing, transmission, or computer storage.

2. MIL-STD-1472C (1981): Feedback should be provided to inform the operator whether: (a) the key was pressed, (b) the intended key was pressed, and (c) the next operation may be initiated.

3.5.2.1.5 Function Control

a. IOS Design Recommendation

Function-control switches should be provided to allow the user (a) to clear only the last posted digit, and (b) to clear all posted digits.

b. Reference

This recommendation is from MIL-HDBK-759A (1981).

3.5.2.2 Alphanumeric Keyboards

3.5.2.2.1 Configuration

a. IOS Design Recommendation

Keyboards used for highly alphabetic text with some numerics should be configured as shown in Figure 3-2. For applications in which the data entry requirements vary from primarily alphabetic to primarily numeric, a keyboard that provides a separate and distinct numeric keypad adjacent to the alphabetic keyboard, preferably on the right-hand side, should be used. Numeric keys should still be provided across the top row of the alphabetic keyboard if possible.

b. References: Requirements

1. Cakir et al. (1980): The QWERTY arrangement is the universal layout for typewriter and terminal keyboards. Two major problems associated with this layout are that (a) in English-language typing, about 60% of the workload is on the left hand, which, for the majority of users, is the nonpreferred side; and (b) only about 30% of the typing is done on the "home"

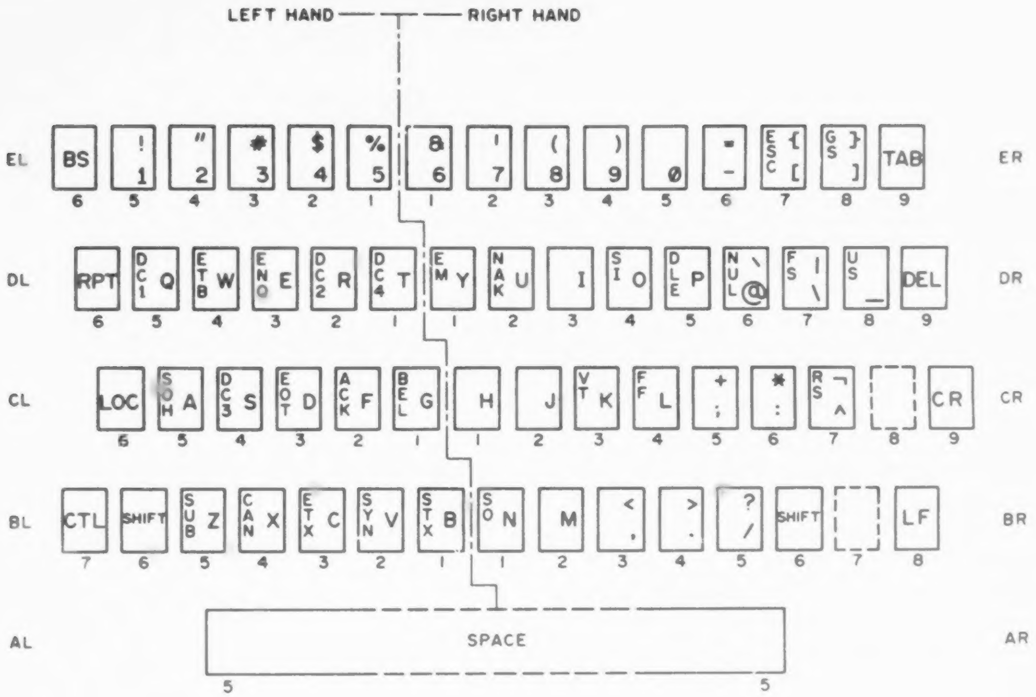

LEFT HAND
RIGHT HAND
EL
BS ! 1 " 2 # 3 $ 4 % 5 & 6 ' 7 (8) 9 0 = - ESC { [GS }] TAB
6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
ER
DL
RPT DC1 Q ETB W ENQ E DC2 R DC4 T EM Y NAK U I SI O DLE P NUL \ @ FS | \ US _ DEL
6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
DR
CL
LOC SOH A DC3 S EOT D ACK F BEL G H J VT K FF L + ; * : RS ¬ ^ CR
6 5 4 3 2 1 1 2 3 4 5 6 7 8 9
CR
BL
CTL SHIFT SUB Z CAN X ETX C SYN V STX B SO N M < , > . ? / SHIFT LF
7 6 5 4 3 2 1 1 2 3 4 5 6 7 8
BR
AL
SPACE
5 5
AR

Figure 3-2. Type I, Class 1 Standard Keyboard Arrangement. (From MIL-STD-1280, 1969.)

row of keys (the A row), whereas about 50% is done on the back row. Attempts to modify the QWERTY layout all involve the placement of the most frequently used keys under the stronger fingers as well as concentrating more of the workload on the right hand. The primary criteria that should be considered in the design of a keyboard layout are as follows:

(a) As many hand changes as possible should be required in the operation of the keyboard.

(b) The letters that occur most frequently in the language should be included in the home row of keys.

(c) The workload should be distributed evenly between the right and left hands, but with a slight emphasis on the use of the right hand.

(d) The workload should emphasize the use of the home row of keys, then the top and bottom rows, in that order.

(e) The ring fingers and little fingers should require the least use; that is, the least frequently used letters should be at the end of the rows.

(f) The number of keying sequences that require the consecutive use of middle/ring and ring/little fingers should be minimized.

(g) Finger spans that are wide and awkward should be avoided or at least minimized.

(h) Keying jumps from the top to bottom row and vice versa should be minimized.

(i) Keying sequences involving the repeated use of any one finger should be kept to the smallest possible number.

2. IBM Corporation (1979): The location of most of the keys on a keyboard is dictated by long-existing standards. These keys can be operated while some of the operator's fingers are in contact with the home keys; i.e., they are in "touch" locations. Special function keys are located in the nontouch area of the keyboard because they should be viewed for verification before they are actuated. Thus, they can be actuated only when the operator's fingers are moved from the home keys.

3. MIL-HDBK-759A (1981): Alphanumeric keysets in a typewriter configuration should be of the QWERTY arrangement and should comply with MIL-STD-1280 (1969). Key action should be of the momentary-contact type.

4. MIL-STD-1472C (1981): The configurations for keyboards used to enter alphabetic and some numeric information should conform to MIL-STD-1280 (1969). For applications in which the data entry varies from primarily alphabetic to primarily numeric, two alternatives are preferred: (a) the keyboard, as shown in Figure 3-3, where there is no separation between alphabetic and numeric characters, or (b) a keyboard with a separation to emphasize the two separate functions, with the numeric keyboard located to the right of the standard alphanumeric keyboard.

5. MIL-STD-1280 (1969): Alphanumeric keyboards are categorized to indicate the area of application and the kind of textual traffic for which the keyboard layout is best suited, as follows (type refers to machine application and class refers to the kind of textual traffic):

(a) Type I is the arrangement for a keyboard that produces a compound, or encoded, electrical output for the subsequent indirect control of another device, such as a teletypewriter or a computer.

(b) Type II is the arrangement for a keyboard that directly controls its associated device, such as a typewriter.

(c) Class 1 is the arrangement for a keyboard for the kind of textual traffic that normally has a high alpha content, such as the usual interoffice correspondence.

(d) Class 2 is the arrangement for a keyboard for the kind of textual traffic that normally has a high numeric content, such as stock lists or data for problem solving.

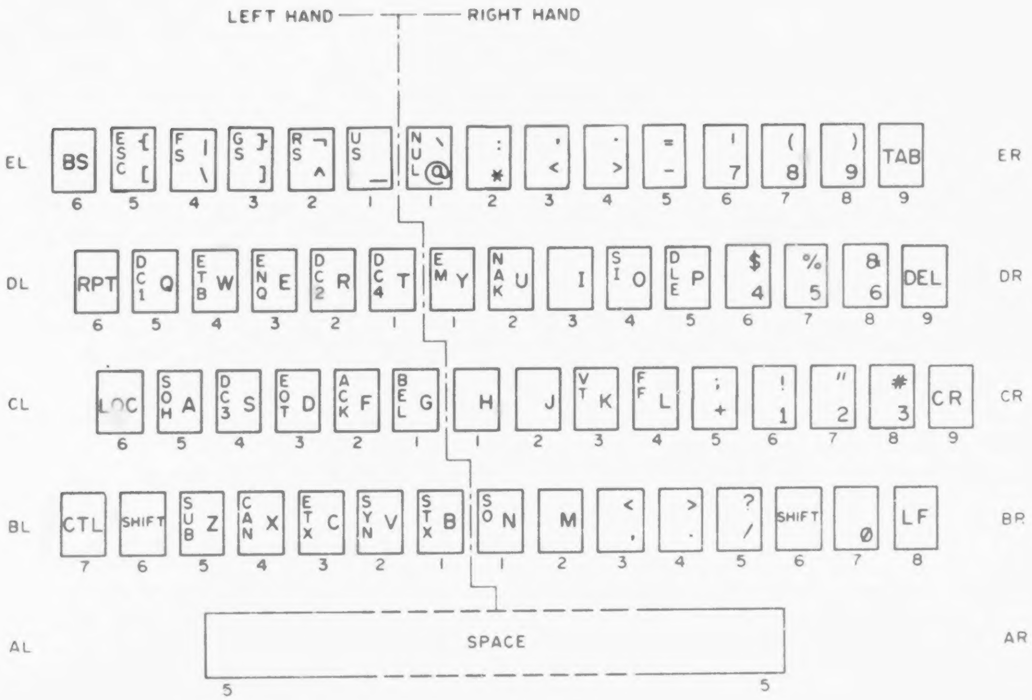


Figure 3-3. Type I, Class 2 Standard Keyboard Arrangement. (From MIL-STD-1280, 1969.)

Overall, three standard alphanumeric keyboard arrangements are identified, each providing a unique Type and Class combination for different machine applications and textual traffic. The three arrangements are as follows:

(a) Type I, Class 1: This is the standard keyboard arrangement for high-alpha-content text applications. The Type I, Class 1 arrangement is illustrated in Figure 3-2.

(b) Type I, Class 2: This is the standard keyboard arrangement for high-numeric-content text applications. Figure 3-3 shows the Type I, Class 2 arrangement.

(c) Type II, Class 1: This is the standard keyboard arrangement for 46-key Optical Character Recognition (OCR) typewriters. The keyboard is presented in Figure 3-4.

Figures 3-2 through 3-4 are intended to demonstrate the nominal, relative positions of the keys. They are not intended to define the physical considerations, such as key spacing, keyboard slope, or the size or shape of the keytops or the space bar. The key position numbers are for reference purposes only. There is a variety of options available in assigning characters and functions to various keys.

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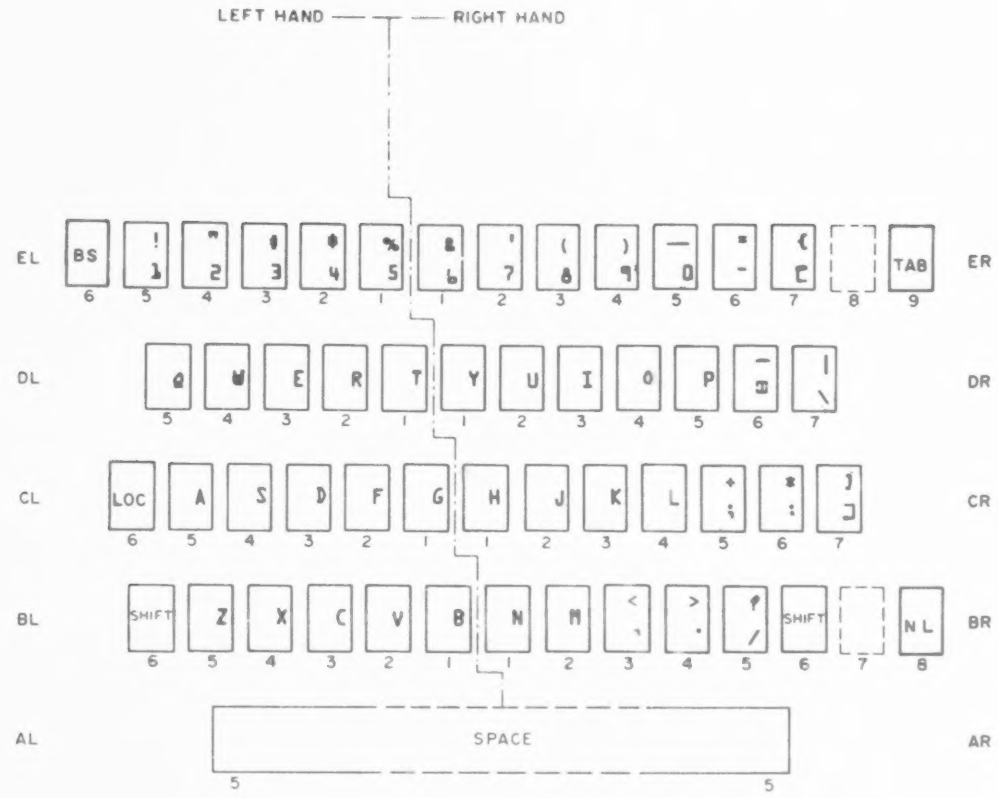


Figure 3-4. Type II, Class 1 Standard Keyboard Arrangement. (From MIL-STD-1280, 1969.)

6. Woodson (1981): The QWERTY arrangement should be used for typewriter keyboards. Spare keys can be utilized for special control function requirements.

3.5.2.2.2 Dimensions, Resistance, Displacement, and Separation

a. IOS Design Recommendation

The dimensions, resistance, displacement, and separation between adjacent edges of the keys for alphanumeric keyboards should conform to the requirements specified in Table 3-6, and they should be uniform for all of the keys on a given keyboard. A force (resistance) adjustment control is recommended on keyboards, to enable the operator to adjust the force to a preferred level. Individual keys should be concave and rounded at the corners. The home-row keys may be more concave than the others, to aid the operator in locating the keys. Each keytop should have a matte finish, to reduce light reflections and to provide a nonslip surface. The keys should have black letters on a white background. Some keys, such as shift, shift lock, space bar, and back space, should have contrasting colors; for example, white on black. Color coding can be an effective aid for the operator in locating the correct keys. The use of functional blocks of keys can also facilitate keyboard operation. No more than two legends should be printed on the keytops, and the legends should not be smaller than the required character size for CRTs. For labeling function keys, abbreviations or codes should be used instead of symbols, except where standard symbols exist.

b. References: Requirements

1. Cakir et al. (1980): The keytops should be square, and the size of the keytops should be between 12 and 15 mm, with a spacing between centers of adjacent keys in the range of 18 to 20 mm. The shape and profile of keytops should (a) aid the accurate location of the user's finger; (b) minimize light reflections; (c) provide a suitable surface for key legends; (d) prevent the accumulation of dirt, dust, moisture, and so forth on the surface or between keys; and (e) be neither sharp nor uncomfortable to press. In general, shape (b) in Figure 3-5 best satisfies these criteria. Also, the keytops should have a matte finish, to reduce reflections off the surface and to provide a nonslip surface. An excessively rough surface, however, might promote a rapid accumulation of dust and grime.

The recommended actuation force for keys is 0.25 to 1.5 N; and the recommended key displacement, or travel, is 0.8 to 8 mm. Color coding of keys can aid the user in locating the correct keys and thereby reduce search times and search errors. Laying out the keys in functional blocks can also facilitate the operation of the keyboard. No more than two legends should be printed on the keytops, assuming a size of 12 to 15 mm. The legends should not be smaller than the minimum acceptable character size for CRT displays; that is, 3 mm. The key legends should be as explicit and as easy to understand as possible. Simple abbreviations are adequate, and it may be desirable to modify the full name of a function instead of trying to fit it on the key top. Abbreviations or codes should be used for labeling function keys except where standard symbols exist. Sensible abbreviations of meaningful functions are easier to remember than symbolic labels. The sizes of the legends should be consistent from key to key.

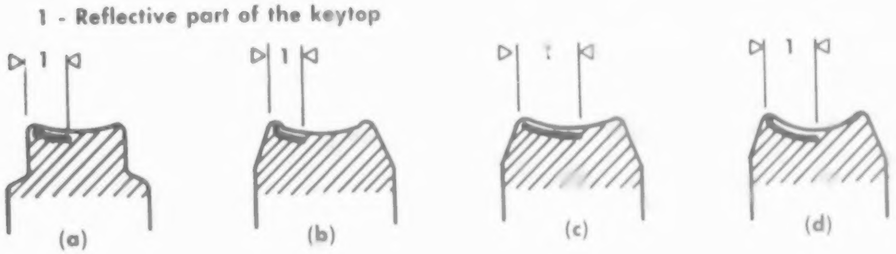


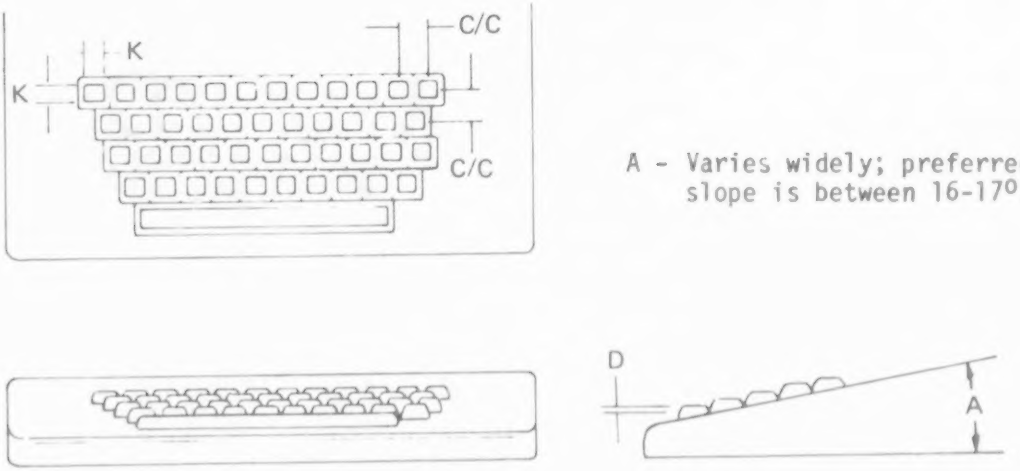
Figure 3-5. Keytop Profiles. (From Visual Display Terminals, [p. 125] by A. Cakir, D.J. Hart, and T.F.M. Stewart, 1980, Chichester, Sussex, England: John Wiley & Sons, Ltd. Copyright 1980 by John Wiley & Sons, Ltd. Reprinted by permission.)

2. IBM Corporation (1979): The key force for modern high-production keyboards is between 15 and 125 g, with a key displacement in the range of 3 to 5 mm. The lighter key forces may be used for more proficient operators. Multiple keys may be actuated, however, if the key force is too small; and some keys may not be actuated if the key force is too great or too much displacement is required. Also, finger fatigue can be induced by excessive force requirements. Keytops are typically about 0.5 in. square and have a slightly concave surface. The home-row keys may be more concave than the other keys, to aid the user in locating the keys. The keytops may have a matte finish, to minimize light reflection and to facilitate the readability of the labels. Keytops with a matte finish are also less slippery to the fingers.

3. MIL-HDBK-759A (1981): The criteria provided in Table 3-6 should be used in the design of alphanumeric keyboards. These criteria should be uniform for all keys on a keyboard. The requirements for alphanumeric keyboards are shown in Figure 3-6.

TYPEWRITER:

K - Key Size = 1.27
C/C - Center/Center Spacing = 1.9 cm
D - Displacement = 0.47 cm for
electric; 0.16cm for typical
manual machine.



A - Varies widely; preferred slope is between 16-17°.

Figure 3-6. Keyboard Requirements.
(From MIL-HDBK-759A, 1981.)

4. MIL-STD-1472C (1981): The dimensions, resistance, displacement, and separation between the adjacent edges of the keys for alphanumeric keyboards should be consistent with the criteria in Table 3-6, and these criteria should be uniform for all of the keys on a given keyboard.

5. Woodson (1981): The actuation force for typical typewriter keys should not exceed about 5 oz (142 g); and the resistance should be at least 2 oz (57 g), to reduce the possibility of inadvertent actuation. A force control adjustment is recommended, especially for mechanical typewriter applications. Individual keys should be concave and rounded at the corners. The keys should have black letters on a white background. Certain keys, such as shift, shift lock, space bar, and back space, should have contrasting colors; for example, white on black. The distance between the centers of adjacent keys should be 0.75 in.

3.5.2.2.3 Keyboard Slope

a. IOS Design Recommendation

Keyboards should be sloped upward toward the back at an angle of between 5° and 30° from the horizontal, and a 17° slope is preferred. A keyboard profile that is stepped, sloped, or dished may be used as shown in Figure 3-7. The thickness of the keyboard, which is the distance from the base to the home row of keys, should be minimized and not exceed about 30 mm. Also, the keyboard should be mounted directly in front of the operator when it is being used.

b. References: Requirements

1. Cakir et al. (1980): A keyboard profile may be stepped, sloped, or dished, as shown in Figure 3-7. The curvature of the keytops in each of the four rows of the dished profile must be slightly different so that the overall dish shape is maintained. This arrangement, combined with deeper depressions of the home-row keys, facilitates keying speed for skilled operators and promotes a sense of user confidence. The keyboard should slope upward toward the back at an angle between 5° and 15°. The thickness of the keyboard should be minimized to reduce the postural loading on the operator by ensuring the correct working level. Keyboard thickness, which is the distance from the base of the keyboard to the home row of keys, should not be greater than about 30 mm.

2. IBM Corporation (1979): The size of the keyboard should be minimized to provide more room for other items on the work surface, and the thickness and height of the keyboard should be minimized to provide adequate knee space. A keyboard slope between 10° and 15° is acceptable, although other slopes may be used for specific applications and locations.

3. MIL-HDBK-759A (1981): The keyboard should be mounted in a location directly in front of the operator when it is being used. The front row of keys should be in the range of 230 to 300 mm above the level

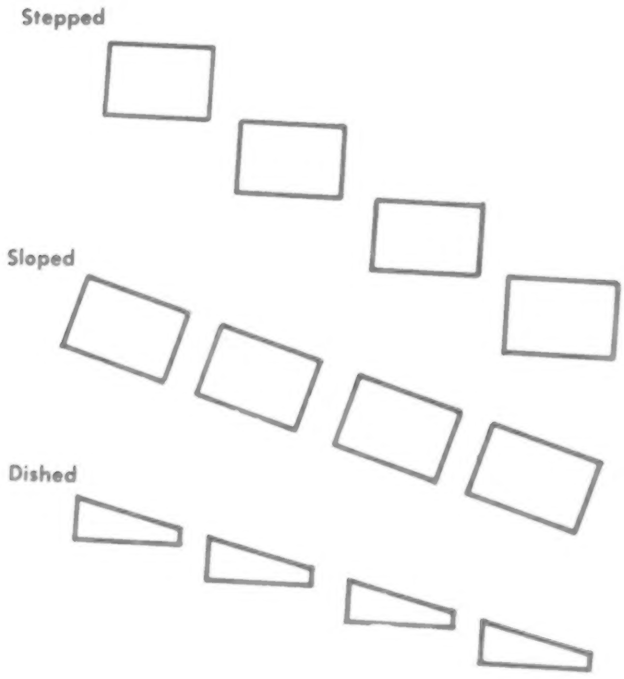


Figure 3-7. Common Keyboard Profiles.
(From Visual Display Terminals [p. 126] by A. Cakir, D.J. Hart, and T.F.M. Stewart, 1980, Chichester, Sussex, England: John Wiley & Sons, Ltd. Copyright 1980 by John Wiley & Sons, Ltd. Reprinted by permission.)

of the seat. The tiers of keys should slope upward toward the back at an angle of between 10° and 30° from the horizontal, although the preferred slope is 17°.

4. MIL-STD-1472C (1981): Nonportable keyboards should have a slope between 15° to 25° from the horizontal, and the preferred slope is 17° to 18°. Portable keyboards may be sloped in accordance with the operator's preference.

5. Woodson (1981): The keyboard should slope upward toward the back at an angle from 15° to a maximum of 25° from the horizontal. Individual keytops should be horizontal and not inclined or sloped.

3.5.2.2.4 Feedback

a. IOS Design Recommendation

When a key is pressed, feedback should be provided to inform the operator that (a) the key was actuated; (b) the intended key selection was the one, in fact, made; and (c) the next operation may be executed. Relatively infrequent and unskilled keying can be accomplished more accurately and rapidly with tactile feedback provided by a collapsing spring or a similar snap-action mechanism. Audible feedback, such as a click or tone, to indicate key actuation can also reduce keying errors. A control for adjusting the auditory signal may be desirable for operators.

b. References: Requirements

1. Cakir et al. (1980): Relatively infrequent and unskilled keying can be accomplished more rapidly and accurately when tactile feedback is provided. A collapsing spring or a similar snap-action mechanism provides positive tactile feedback to aid operator keying performance. Tactile feedback appears less important for skilled operators, although some feedback may be beneficial. If a snap action is too positive, errors may actually increase for experienced operators. Audible feedback or clicks to indicate key actuation can reduce undetected errors for skilled and unskilled operators.

2. IBM Corporation (1979): The optimum force/displacement characteristics of a key require a steadily increasing force as the key is depressed until it is actuated; immediately beyond the point of activation the force diminishes sharply, then steadily increases again. A click or tone may be used in connection with the keyboard to provide auditory feedback, and the audible signal may be adjustable.

3. MIL-HDBK-759A (1981): Feedback should be provided when the keys are pressed, to inform the operator whether (a) the key was, in fact, actuated; (b) the intended key was the one actually selected; and (c) an entire message or message segment is ready for the next operation, such as filing, transmission, and computer storage.

4. MIL-STD-1472C (1981): When a key is pressed, feedback should be provided to inform the operator whether (a) the key was actuated, (b) the intended key was pressed, and (c) the next operation may be initiated.

3.5.2.2.5 Function Control

a. IOS Design Recommendation

A convenient method of switching keyboard function and indicating keyboard state should be provided to permit the user (a) to compose and post message text before it is released, (b) to edit posted data or text material, and (c) to directly enter data or instructions into a computer.

b. Reference

This design requirement is contained in MIL-HDBK-759A (1981).

3.5.3 Keysets

The following design guidelines for dedicated and multifunction keysets were extracted from MIL-HDBK-759A (1981).

3.5.3.1 Dedicated Keysets

3.5.3.1.1 Configuration

A dedicated keyset provides two or more pushbutton sets that are grouped together because of some commonality of purpose and that utilize some common control and/or display functions. The key action may be momentary contact or latching, whichever best serves the control purpose; and keytops may (a) be opaque, (b) contain an indicating lamp, (c) provide a continuously illuminated label, or (d) provide an illuminated label only when activated.

3.5.3.1.2 Dimensions, Displacement, and Separation

Dedicated keysets that have switchcap labels should conform to the requirements for legend switches, and those that do not have switchcap labels should conform to the dimensional requirements for keyboards. The displacement requirements do not apply to touch-activated pushbuttons.

3.5.3.1.3 Actuation Force

The force required to actuate dedicated keysets should be in the range of 0.25 to 11.3 N. The larger forces should be used only with large-size illuminated switchcaps (25 mm wide or larger), if needed to accommodate the switchcap labeling. The preferred force is about 2.8 N.

3.5.3.1.4 Feedback

Feedback should be provided to inform the operator whether (a) the key that was depressed was, in fact, actuated; (b) the intended key selection was the one actuated; (c) the system is processing a response to the key activation; and (d) the system has completed its response to the key actuation.

3.5.3.1.5 Mounting

The keysets may be mounted wherever they are most convenient to use.

3.5.3.2 Multifunction (Programmable) Keysets

3.5.3.2.1 Special Requirements

Multifunction keysets require switching at two levels: (a) a gross function, or mode level; and (b) a detailed, or item, level within each mode.

a. Function (Mode) Selection: The function selectors should ordinarily be rotary selectors or interlocked pushbuttons with latching actuation. The complete range of switch choices, as well as the active mode, should be visible to the operator at all times. The requirement does not apply when function selectors are implemented by entry of coded switching instructions using a general-purpose keyboard. Mode switching may also be implemented for activation by a computer, in which case the manual switching capability can be correspondingly reduced.

b. Item Selection: For item selection, pushbuttons of the appropriate types, such as latching or momentary and interlocked or independent, should be used for the specific switching functions.

c. Item Labeling and Feedback: The item labels that correspond to the selected mode should be displayed on or adjacent to the item selector switch, and labels that are not applicable to the selected mode should not be visible. Feedback should be provided to indicate the current state of each item selector switch. Feedback should also be provided to indicate the current state of each switch function after switching to a new mode. Additionally, feedback may be required to indicate which switches can or cannot be used in the current mode; for example, by extinguishing labels for nonapplicable switch functions.

3.5.3.2.2 Configuration

The configuration of the keyset should be compatible with the switch functions it must provide and with the operator's task. A sample configuration for Army-type applications is provided in Figure 3-8.

3.5.3.2.3 Dimensions, Displacement, and Separation

The dimensions, displacement, and separation requirements for pushbuttons (paragraph 3.3.3) should be used for the pushbuttons in multifunction keysets as appropriate.

3.5.3.2.4 Actuation Force

Pushbuttons used in multifunction keysets should have an actuation force in the range of 0.25 to 11.3 N, although the preferred force is 2.8 N. The larger forces should be used only with large-size illuminated switchcaps (2.5 cm wide or larger), which may be required to accommodate the switchcap labeling.

3.5.3.2.5 Mounting

The keysets may be mounted wherever they are most convenient to use.

3.5.4 Menu Selectors

The following guidelines for the design of menu selectors are from MIL-HDBK-759A (1981).

3.5.4.1 Special Requirements

Menu selectors require controls for three levels of switching: (a) function-level controls for selecting from a set of menu listings the one that is to be displayed, (b) controls for selecting a particular item from the menu, and (c) a control for entry and/or activation of the menu item

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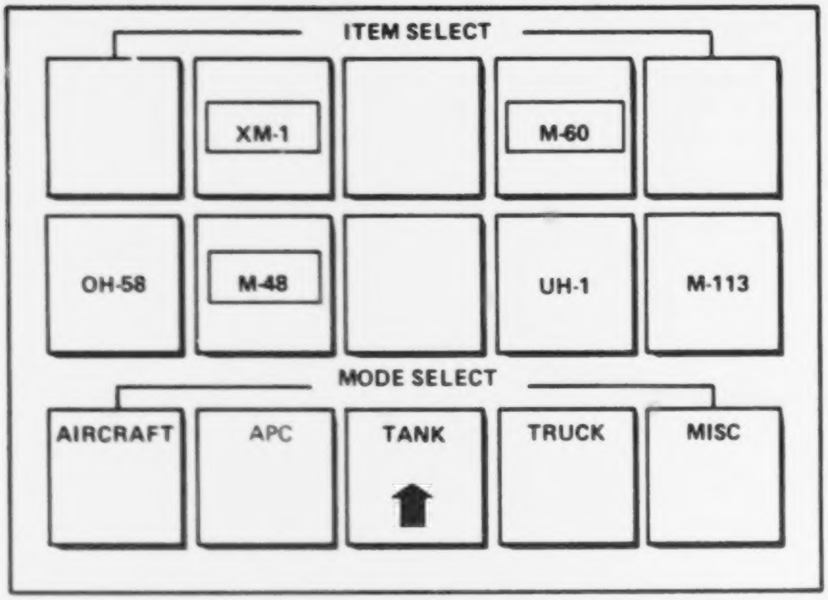
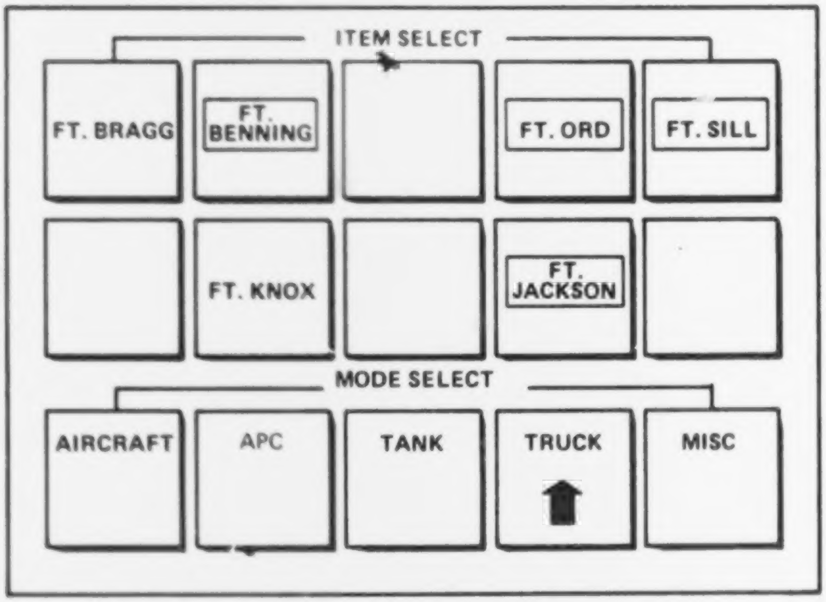

ITEM SELECT
XM-1
M-60
OH-58
M-48
UH-1
M-113
MODE SELECT
AIRCRAFT
APC
TANK
TRUCK
MISC

ITEM SELECTORS (E.G., PUSH BUTTON SWITCHES WITH (MULTIPLE) PROJECTED LEGENDS

FUNCTION OR MODE SELECTORS (E.G., SPLIT-HALF PUSH BUTTONS)

EXAMPLE 1
(VEHICLE MODE)


ITEM SELECT
FT. BRAGG
FT. BENNING
FT. ORD
FT. SILL
FT. KNOX
FT. JACKSON
MODE SELECT
AIRCRAFT
APC
TANK
TRUCK
MISC

*NOTE: BORDERS ARE PROJECTED AROUND ITEMS THAT HAVE BEEN SELECTED (FEEDBACK INFORMATION)

EXAMPLE 2
(INSTALLATION MODE)

Figure 3-8. Multifunction Keyset Format Examples.
(From MIL-HDBK-759A, 1981.)

selected. The function selector should be implemented as described in paragraph 3.5.3.2.1a. Selection of the menu item may be made with a cursor that is controlled by pushbuttons, thumbwheel, light pen, or grid/stylus control. A momentary-contact switch should be used for the entry/activation controller.

3.5.4.2 Configuration

The configuration of the menu-selector controls and displays should be consistent with the required switching functions and operator's task. Two sample configurations for Army-type applications are provided in Figure 3-9.

3.5.4.3 Dimensions, Displacement, and Separation

The dimensions, displacement, and separation of pushbuttons should conform to the requirements for legend switches. If thumbwheel controls are used, they should conform to the requirements for thumbwheels.

3.5.4.4 Actuation Force

Pushbutton and thumbwheel control actuation forces should be in the ranges specified for these control devices.

3.5.4.5 Feedback

Feedback should be provided as required by paragraphs 3.5.2.2.4 and 3.5.3.2.1. Some method, such as underlining, should be used to enable the operator to easily distinguish the selected menu items from the nonselectable items.

3.5.4.6 Mounting

The cursor controller (e.g., thumbwheel or keypad) should be mounted below the menu listing. The item-activation button should be adjacent to the cursor controller, preferably on the right-hand side. The function or mode selector should be mounted in a convenient location near the cursor controller.

3.6 Toggle Switches

3.6.1 Applications

a. IOS Design Recommendation

Toggle switches may be used for functions requiring two discrete positions, such as ON/OFF and START/STOP operations. A three-position toggle switch may be used when three discrete positions are required, such as AUTOMATIC/MANUAL/OFF, but a rotary selector or pushbutton array is generally preferred for these applications unless space is severely limited. A four-position toggle switch should not be used.

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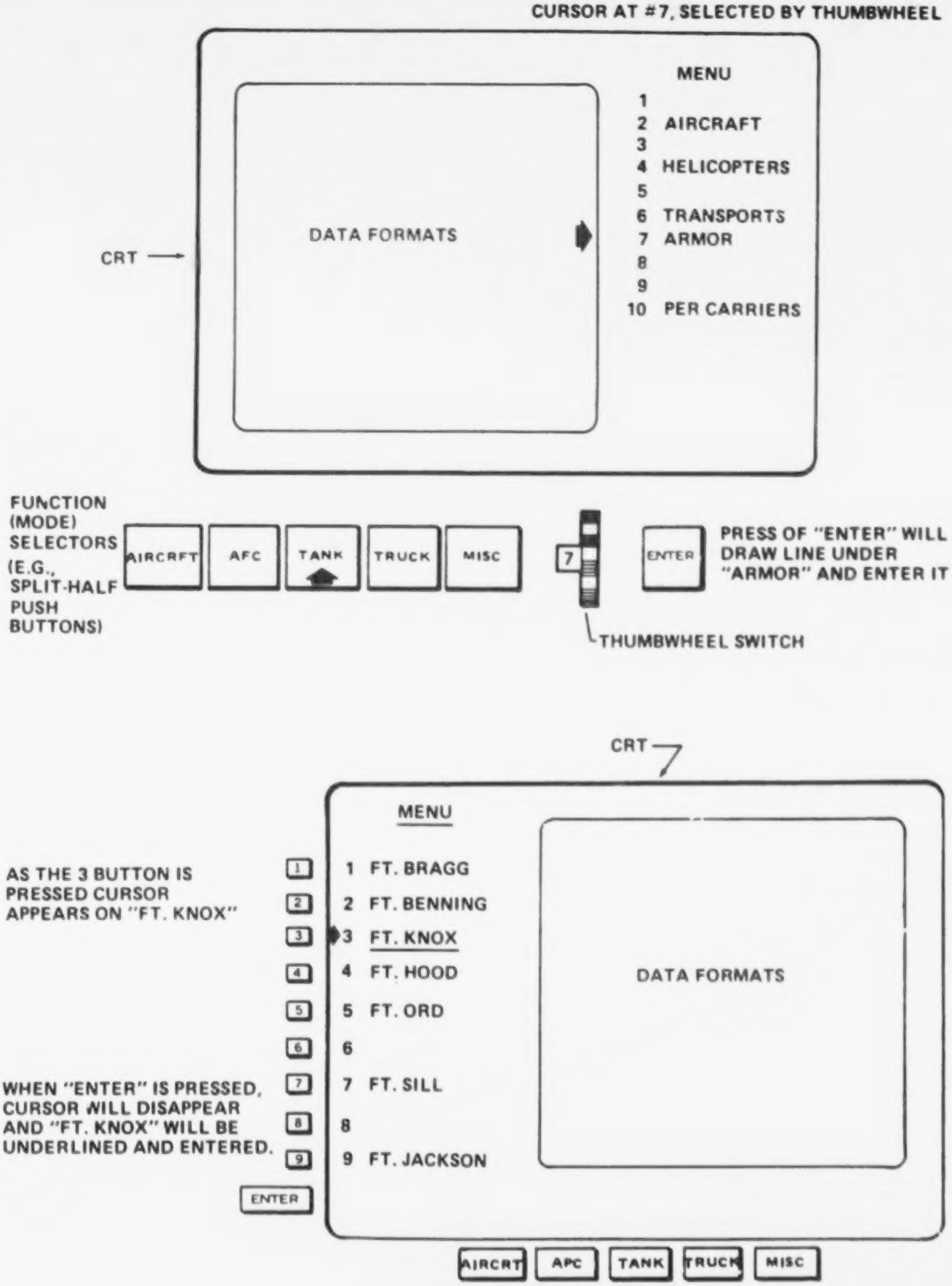
CURSOR AT #7, SELECTED BY THUMBWHEEL
MENU
1
2 AIRCRAFT
3
4 HELICOPTERS
5
6 TRANSPORTS
7 ARMOR
8
9
10 PER CARRIERS
DATA FORMATS
CRT
FUNCTION (MODE) SELECTORS (E.G., SPLIT-HALF PUSH BUTTONS)
AIRCRFT
AFC
TANK
TRUCK
MISC
7
ENTER
PRESS OF "ENTER" WILL DRAW LINE UNDER "ARMOR" AND ENTER IT
THUMBWHEEL SWITCH
CRT
MENU
AS THE 3 BUTTON IS PRESSED CURSOR APPEARS ON "FT. KNOX"
1
2
3
4
5
6
7
8
9
1 FT. BRAGG
2 FT. BENNING
3 FT. KNOX
4 FT. HOOD
5 FT. ORD
6
7 FT. SILL
8
9 FT. JACKSON
DATA FORMATS
WHEN "ENTER" IS PRESSED, CURSOR WILL DISAPPEAR AND "FT. KNOX" WILL BE UNDERLINED AND ENTERED.
ENTER
AIRCRT
APC
TANK
TRUCK
MISC

Figure 3-9. Menu Selector Types and Format Examples. (From MIL-HDBK-759A, 1981.)

b. Reference: Requirements

1. MIL-HDBK-759A (1981): Toggle switches may be used for functions requiring two discrete positions. A three-position toggle switch may be used when three discrete positions are required, although a rotary selector or pushbutton array is usually preferred for this application.

2. MIL-STD-1472C (1981): Toggle switches should be used for functions requiring two discrete positions and/or where there are severe space limitations. Three-position toggle switches should be used only when it is not feasible to use a rotary control, legend switches, and so forth, or when the toggle switch is spring loaded and the center position is OFF.

3. Woodson (1981): Standard two-position toggle switches should be used for START/STOP and ON/OFF operations. A momentary (spring-return) toggle switch should be used for check-reading an instrument or circuit, or for a slewing operation. A three-position toggle switch should be used for combining alternatives of a single function, such as AUTOMATIC, MANUAL, or OFF. A four-position toggle switch should not be used unless absolutely necessary, because of space limitations.

3.6.2 Accidental Activation

a. IOS Design Recommendation

Channel guards, lift-to-unlock switches, or other equivalent devices should be used when the prevention of accidental activation is of primary importance because critical, dangerous, or hazardous conditions might result. The use of lock wire should be avoided. The maximum resistance of lift-to-unlock devices should be 13 N. The location of cover guards in the open position should not interfere with the operation of the protected switch or adjacent controls.

b. References: Requirements

1. MIL-HDBK-759A (1981): When the prevention of accidental activation is of primary importance because critical, dangerous, or hazardous conditions might result, channel guards, lift-to-unlock switches, or any other equivalent means should be provided.

2. MIL-STD-1472C (1981): When the prevention of accidental activation is of primary importance because critical, dangerous, or hazardous conditions might result, channel guards, lift-to-unlock switches, or other equivalent prevention mechanisms should be used. Safety or lock wire should not be used. The resistance of lift-to-unlock devices should not exceed 13 N. If a cover guard is used, its location in the open position should not hinder the operation of the protected switch or adjacent controls.

3. Woodson (1981): The hazards associated with accidental contact of the toggle switch should be considered. Lock switches or covers should be used to prevent inadvertent operation.

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3.6.3 Dimensions, Displacement, Resistance, and Separation

a. IOS Design Recommendation

The dimensions, displacement, and separation between adjacent toggle switches should be consistent with the criteria presented in Table 3-7. Switch resistance should increase gradually, then drop as the switch snaps into position. The resistance should be in a range of 2.8 to 11 N, depending on the length of the switch handle. The switch should not be capable of being stopped between positions.

b. References: Requirements

1. MIL-HDBK-759A (1981): The dimensions, displacement, and separation between adjacent toggle switches should conform to the criteria in Table 3-7. Switch resistance should increase gradually, then drop as the switch snaps into position. The resistance should be in a range of between 2.8 and 11 N, depending on the length of the switch handle.

2. MIL-STD-1472C (1981): The dimensions, resistance, displacement, and separation between adjacent edges of toggle switches should conform to the criteria in Table 3-8. Switch resistance should increase gradually, then drop as the switch snaps into position. The switch should not be capable of being stopped between positions.

3. Woodson (1981): There is a variety of toggle switch shapes and sizes, and most are satisfactory. The "throw" or displacement of the switch should be at least 30° so that the position of the switch can be determined at a glance. The handle of a toggle switch should be at least 1.3 cm in length, and preferably no longer than 2.5 cm. The resistance should not exceed about 227 g for the smaller, shorter switch handles, and 425 g for larger ones. When several switches are used horizontally in rows or vertically in columns, the center-to-center horizontal separation between switches should be 1.9 cm, and the center-to-center vertical spacing between switches should be 3.2 cm. The minimum diameter of the switch handle is .32 cm, and the external housing from which the handle protrudes should be between 0.5 and 2.5 cm in depth. There are four typical handle shapes generally available: (a) a tapered handle; (b) a straight, cylindrical handle; (c) a handle with a small ball shape on the outer end; and (d) a handle with a relatively wide, flat end. The first is the most typical. The second is characteristic of most small toggle switches. This is not a desirable shape, however, when the handle is long, because injury can result if the operator bumps into it. The third handle provides additional tactile cues when it is used in darkness. The fourth handle is especially good because it is easy to identify the switch position and because it can be obtained in different colors for color-coded applications. Three-position toggle switches are not recommended. The 30° throw requirement cannot be maintained with three switch positions. Some other type of switch should be used in preference to a toggle when three or more switch positions are required.

Table 3-7. Toggle Switch Design Criteria (From MIL-HDBK-759A, 1981.)

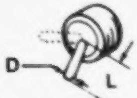
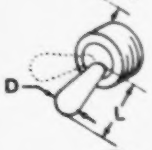
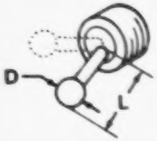
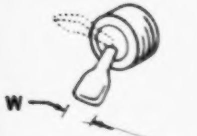
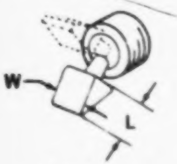
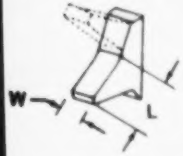
	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	MINIATURE TOGGLE SWITCH: LIMIT USE TO INDOOR APPLICATIONS WHERE LIMITED PANEL SPACE PRECLUDES STD SIZE COMPONENTS.	D - MIN DIAM = 3.3mm	L - MIN LENGTH = 13mm			
	STANDARD CONFIGURATION: USE LARGER SIZES FOR APPLICATIONS WHERE GLOVED OPERATION IS LIKELY.	D - MIN DIAM = 4.5mm MAX = 7.8mm	LENGTH MIN - 13mm MAX - 50mm			
	BALL CAP DESIGN APPLICABLE WHERE FIRM GRASP OF TOGGLE IS NEEDED DUE TO VEHICLE/OPERATION OSCILLATION.	D - MIN BALL DIAM = 4.5mm MAX = 7.8mm*	SAME AS ABOVE			
	FLAT OR APPLIED TAB HANDLES PROVIDE IMPROVED VISUAL POSITION REFERENCE WHEN OPERATIONALLY IMPORTANT.			W - MIN HANDLE WIDTH = 4.5mm		
	APPLIED TAB HANDLE PROVIDES MEANS FOR COLOR CODING.		L - 10mm PREFERRED MAX - 25mm	W - 10mm PREFERRED (MIN = 4.8mm MAX = 19mm)		
	ALTERNATE TO ANY STD SIZE CONFIGURATION ABOVE.		SAME AS ABOVE	SAME AS ABOVE		

Table 3-7. Toggle Switch Design Criteria (cont'd)

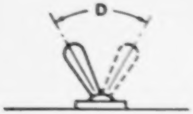
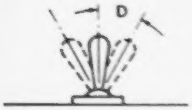
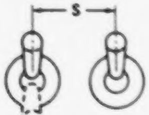
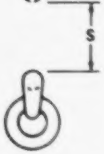
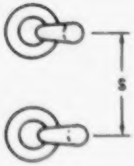
	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	TWO-POSITION SWITCHES ONLY WHEN VISUAL RECOGNITION OF SWITCH POSITION MANDATORY.				D - DISPLACEMENT ANGLE MIN. = 25°	
	THREE-POSITION SWITCHES.				D - DISPLACEMENT MIN = 18°; PREFER 25°	
	SIDE BY SIDE ARRANGEMENT VERTICAL DISPLACEMENT.					S - CTR - CTR* MIN = 19mm MAX FOR SIMULTANEOUS, MULTI-FINGER USE = 28mm.
	TIP TO TIP SEPARATION					S - MIN = 25mm
	VERTICAL ARRAYS					S - MIN = 25mm* *NOTE: ADD 13mm FOR GLOVES.

Table 3-7. Toggle Switch Design Criteria (cont'd)

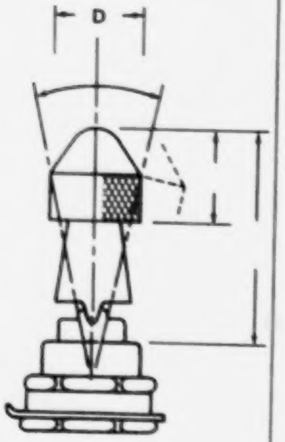
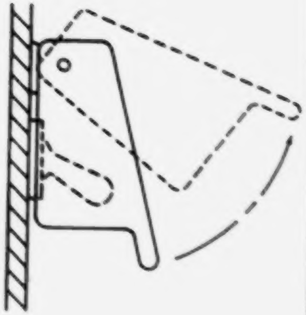
	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	TYPICAL TWO-STEP INTERLOCKING SAFETY SWITCH.	D - MIN = 10mm				SHOULD NOT BE CLOSER THAN 50mm TO OTHER CONTROL OR STRUCTURE.
	ALTERNATE COVER GUARD SWITCH. COVER EASILY COLOR-CODED. NOT APPLICABLE FOR MINIATURIZED TOGGLES.					MAY BE SPACED (HORIZ) AS CLOSE AS 13mm 25mm FOR GLOVES.

Table 3-7. Toggle Switch Design Criteria (concluded)

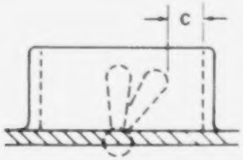
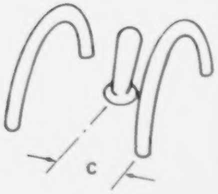
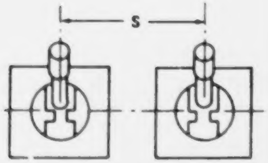
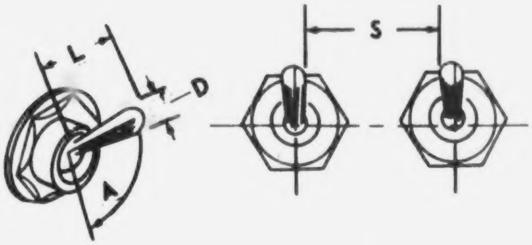
	APPLICATION CRITERIA	DESIGN CRITERIA				
		DIMENSIONS			DISPLACEMENT	SEPARATION
	GUARD SWITCHES WHERE ACCIDENTAL DISPLACEMENT OF A SWITCH MAY UNDESIRABLE (NOT NECESSARILY DANGEROUS)	C - TIP-GUARD FINGER CLEARANCE = MIN 13mm				
		C - MIN = 25mm 32mm FOR GLOVES				
	USE TWO-MOTION SAFETY SWITCH WHEN SWITCH-USE ERROR COULD LEAD TO DANGEROUS CONSEQUENCE. (PULL TO OPERATE)					S - MIN = 25mm (50mm PREFERRED) ADD 13mm FOR GLOVES

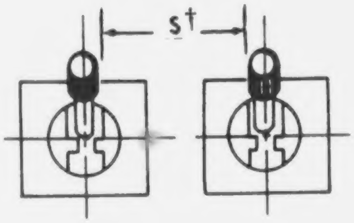
Table 3-8. Toggle Switch Design Criteria (From MIL-STD-1472C, 1981.)

	Dimensions		Resistance		
	Arm length(L)				
	Bare finger	Heavy mittens	Control tip (D)	Small switch	Large switch
Minimum	13 mm	38 mm	3 mm	2.8 N	2.8 N
Maximum	50 mm	50 mm	25 mm	4.5 N	11 N

	Displacement Between Positions (A)	
	2 Position	3 Position
Minimum	525 mrad (30°)	295 mrad (17°)
Maximum	1400 mrad (80°)	700 mrad (40°)
Preferred	-	435 mrad (25°)

	Separation (S)			
	Single finger operation	Lever lock toggle switch	Single finger sequential operation	Simultaneous operation by different fingers
Minimum	19 mm	25 mm	13 mm	16 mm
Optimum	50 mm	50 mm	25 mm	19 mm





3.6.4 Actuation Feedback

a. IOS Design Recommendation

Toggle switches should snap into position with an audible click to provide feedback that the switch has been properly activated. An associated or integral light may also be used for feedback.

b. References: Requirements

1. MIL-HDBK-759A (1981): Toggle switches should snap into position with an audible click to provide positive feedback that the switch has been properly activated. This requirement does not apply to three-position, spring-centering toggle switches.

2. MIL-STD-1472C (1981): An indication of control activation should be provided, such as a snap feel, an audible click, or an associated or integral light.

3. Woodson (1981): Toggle switches should snap into position with an audible click.

3.6.5 Switch Orientation

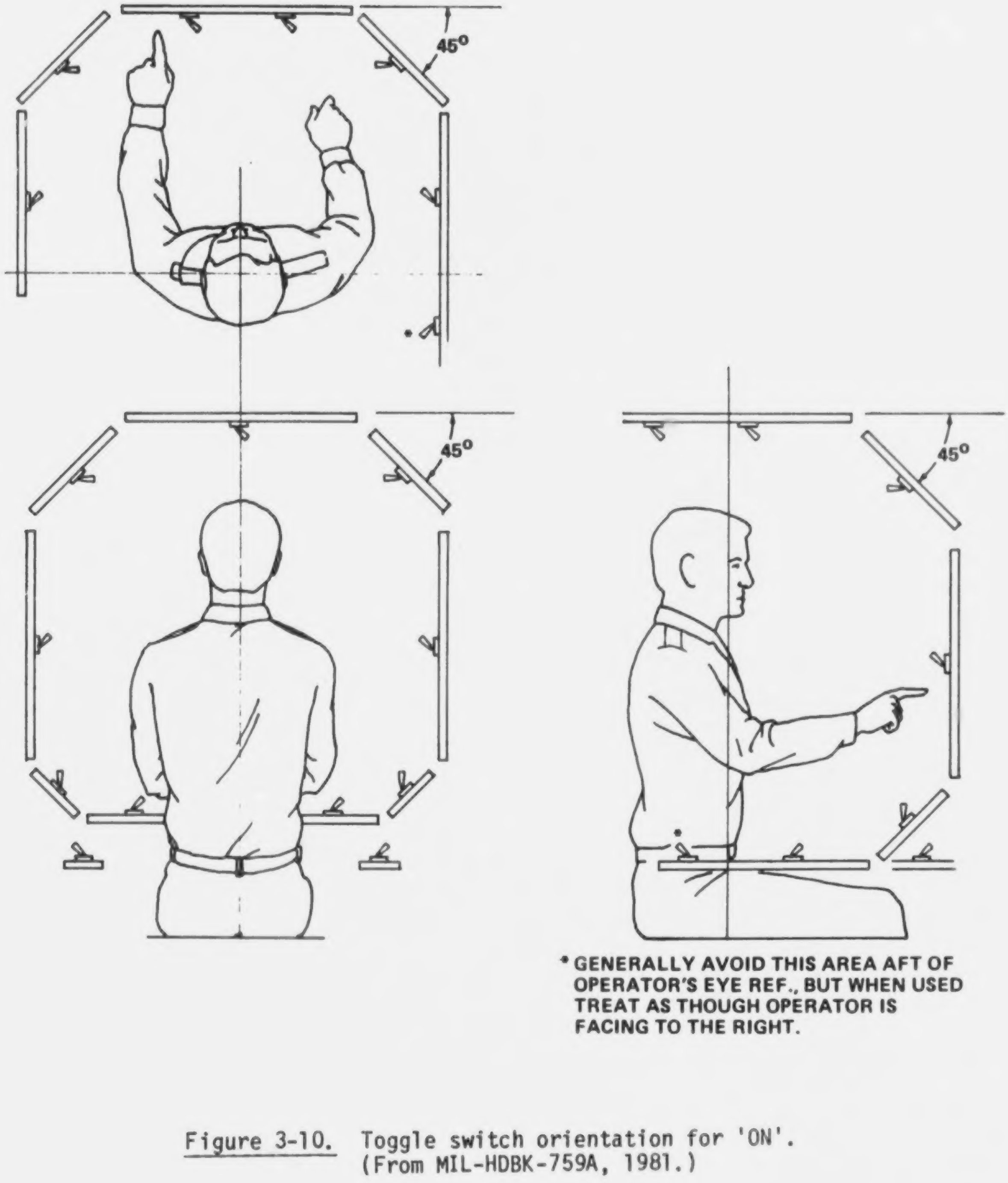
a. IOS Design Recommendation

Generally, toggle switches used for ON/OFF functions should be oriented vertically so that the handle moves in a vertical plane. Toggle switches may be oriented horizontally only if there is a special requirement for lateral movement to provide compatibility with the controlled function or equipment location or due to lack of panel space. Figure 3-10 shows the preferred orientation and direction of movement for toggle switches used on wraparound or vertically stacked workstations. The ON position of the switches should be up, forward, or to the right.

b. References: Requirements

1. MIL-HDBK-759A (1981): Toggle switches used for ON/OFF functions should be oriented vertically so that the handle moves in a vertical plane--unless there is a special requirement for the switch to move laterally in a horizontal plane, such as a lack of panel space or a need to reflect a left-to-right relationship to some display. The ON position should be up, forward, or to the right. Toggle switch location on wraparound or vertically stacked workstations should be oriented to move in the directions indicated in Figure 3-10.

2. MIL-STD-1472C (1981): Toggle switches should be oriented vertically with OFF in the down position. Horizontal orientations of toggle switches should be used only to provide compatibility with the controlled function or equipment location.



* GENERALLY AVOID THIS AREA AFT OF OPERATOR'S EYE REF., BUT WHEN USED TREAT AS THOUGH OPERATOR IS FACING TO THE RIGHT.

Figure 3-10. Toggle switch orientation for 'ON'. (From MIL-HDBK-759A, 1981.)

3.7 Rocker Switches

3.7.1 Applications

a. IOS Design Recommendation

Rocker switches may be used as an alternative to toggle switches for functions that require two discrete positions; for example, ON/OFF and START/STOP. They should be considered for use in applications where toggle switch handles might snag the operator's sleeve or phone cord or where there is not sufficient space for the separate labeling of switch positions. Three-position rocker switches should be used only when they are spring loaded with the center position being OFF or where it is not feasible to use a rotary control, legend switches, and so forth.

b. References: Requirements

1. MIL-HDBK-759A (1981): Rocker switches may be used for functions requiring two discrete positions as an alternative to toggle switches. They should be considered for use where the toggle switch handle might snag the operator's sleeve or phone cord, or where panel space is insufficient for separate switch position labeling. Rocker switches, however, are somewhat vulnerable to accidental activation by brushing-type contacts. Three-position rocker switches should be used only where it is not feasible to use a rotary control, legend switch control, and so forth, or when the rocker switch is spring loaded with the center position being OFF.

2. MIL-STD-1472C (1981): Rocker switches may be used instead of toggle switches for functions requiring two discrete positions. They may be used where toggle switch handles might snag the operator's sleeve or phone cord, or where there is insufficient panel space for separate labeling of switch positions. Three-position rocker switches should be used only where it is not feasible to use a rotary control, legend switch control, and so forth, or when the rocker switch is spring loaded with the center position being OFF.

3. Woodson (1981): Rocker switches provide a good physical indication of switch position and are good substitutes for toggle switches. Rocker switches are preferred to toggle switches when the switches are arranged horizontally, because toggle switches tend to snag the operator's clothing when there is a requirement to reach across the switch assembly.

3.7.2 Dimensions, Displacement, Resistance, and Separation

a. IOS Design Recommendation

The dimensions, displacement, resistance, and separation between adjacent rocker switches should conform to the criteria in Table 3-9. Switch resistance should gradually increase, then drop as the switch snaps into position. The switch should not be capable of being stopped between positions.

b. References: Requirements

1. MIL-HDBK-759A (1981): The dimensions, displacement, and separation between adjacent rocker switches should be consistent with the criteria contained in Table 3-9. The resistance should increase gradually, then drop as the switch snaps into position. The switch should not be capable of being stopped between positions.

2. MIL-STD-1472C (1981): The dimensions, displacement, resistance, and separation between the centers of rocker switches should conform to the requirements presented in Table 3-9. The resistance should increase gradually, then drop as the switch snaps into position. The switch should not be capable of being stopped between positions.

3. Woodson (1981): To provide effective visual identification of switch position, rocker switch handles should be sloped 30° from the nominal plane; and the nominal plane should be at least 0.32 cm above the plane of the panel on which the switch is mounted. Broad rocker switches may be used to provide space for labeling, or narrow handles may be used. Whichever size handle is used, however, the switch centers should not be closer than 1.9 cm when they are arranged side by side. Switch resistance should be in the range of 227 to 340 g.

3.7.3 Switch Orientation

a. IOS Design Recommendation

Rocker switches should be oriented such that the switch handle moves in a vertical plane. Horizontal switch handle movement should be avcided, except in special cases to provide movement compatibility with a display. The ON position of the switch should be up, forward, or to the right. Three-position rocker switches should be avoided.

b. References: Requirements

1. MIL-HDBK-759A (1981): Rocker switches used for ON/OFF functions should be vertically oriented so that the switch handle moves in a vertical plane. Rocker switches may be mounted horizontally in special cases where lateral motion is to be related to a left-right display relationship. The ON position should be up, forward, or to the right. Three-position rocker switches should not be used.

2. MIL-STD-1472C (1981): Rocker switches should be vertically oriented when practicable. Depressing the upper wing of the switch handle should turn the equipment or component on, cause the quantity to increase, or cause the equipment or component to move forward, clockwise, to the right, or up. Rocker switches should be horizontally oriented only to provide compatibility with the controlled function or equipment location.

3.7.4 Feedback

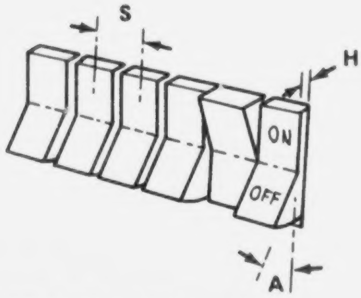
a. IOS Design Recommendation

An indication of control activation should be provided, such as a snap feel, an audible click, or an associated or integral light.

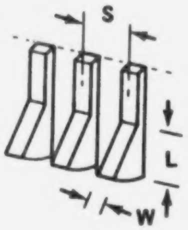
Table 3-9. Rocker Switch Design Criteria (From MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

	Dimensions			
	Width (W)	Length (L)	Resistance	Source
Minimum	6.5 mm 6 mm	13 mm 13 mm	2.8 N 2.8 N	MIL-HDBK-759A, 1981 MIL-STD-1472C, 1981
Maximum	-	-	11.1 N 11 N	MIL-HDBK-759A, 1981 MIL-STD-1472C, 1981

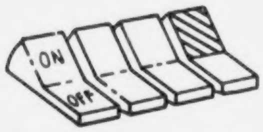
	Displacement		Separation (S) (center-to-center)		
	Depressed (H)	Angle (A)	Bare Hand	Gloved Hand	
Minimum	32 mm 3 mm	30° 30°	19 mm 19 mm	32 mm 32 mm	MIL-HDBK-759A, 1981 MIL-STD-1472C, 1981



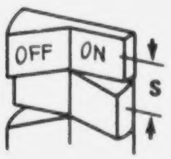
STANDARD ROCKER SWITCH: USE AS ALTERNATE TWO-POSN TOGGLE SWITCH TO PROVIDE LABELING SURFACE, EASE OF COLOR CODING, SWITCH ILLUMINATION.



NARROW WIDTH, ESPECIALLY DESIRABLE FOR TACTILE DEFINITION WITH GLOVES.



ALTERNATE (CONTRAST) COLOR FOR ON VERSUS OFF TO PROVIDE CONSPICUOUS CUE OF SWITCH POSITION. ILLUMINATED "ON" DESIRABLE AS SECOND FEEDBACK CUE.



b. References: Requirements

1. MIL-STD-1472C (1981): Positive feedback of control activation should be provided, such as a snap feel, an audible click, or an associated or integral light.

2. Woodson (1981): Rocker switches should snap into position with an audible click to provide an indication of switch activation.

3.7.5 Accidental Activation

a. IOS Design Recommendation

To prevent the accidental activation of rocker switches, channel guards or equivalent protective measures should be provided.

b. Reference

The recommendation for preventing accidental activation of rocker switches is from MIL-STD-1472C (1981).

3.7.6 Color and Illumination

a. IOS Design Recommendation

Different-colored rocker switches may be used to aid the operator in differentiating them, and alternate colors may be used for either the ON or OFF portions of the handles to denote switch position. Switch color coding should conform to the criteria for transilluminated displays. Rocker switches should be internally illuminated when the display luminance from ambient illumination is below 1 fL.

b. References: Requirements

1. MIL-HDBK-759A (1981): The ON and OFF positions of rocker switches may be denoted using alternate colors. To provide positive recognition of the position the rocker switch is currently in, alternate illumination of either the ON or OFF switch position may be used.

2. MIL-STD-1472C (1981): Rocker switches may utilize alternate colors to denote the ON and OFF switch positions. Also, the switch positions may be alternately illuminated to facilitate the positive identification of the current switch position. Switch color coding should conform to the criteria for transilluminated displays. Rocker switches should be internally illuminated to use in areas where the ambient illumination provides a display luminance below 3.5 cd/m^2 (1 fL). Digits and letters used on switch handles should appear as illuminated characters on an opaque background, and their dimensions should be approximately as follows: (a) height: 4.8 mm, (b) height-to-width ratio: 3:2, and (c) height-to-stroke-width ratio: 10:1.

3. Woodson (1981): An illuminated rocker switch should be used in preference to a toggle switch where the illumination conditions make it impossible to see the position of the toggle, if visibility is critical. Rocker switches are typically obtainable in different colors to provide color coding and facilitate discrimination. In addition, the two wing handles are usually obtainable in two different colors to assist the operator in identifying which switches are activated and which switches are not.

4. CONTROL PLACEMENT

4.1 Introduction

Manual controls should be placed where they can be seen, reached, and activated with minimum operator exertion. The placement of controls used in the normal course of IOS operations should not require the operator to stand, stretch, or move large distances. In this section on control placement, the dimensions of the manual control space for a seated operator are provided. Guidelines are presented for placing primary, secondary, and emergency controls in the operator's control space.

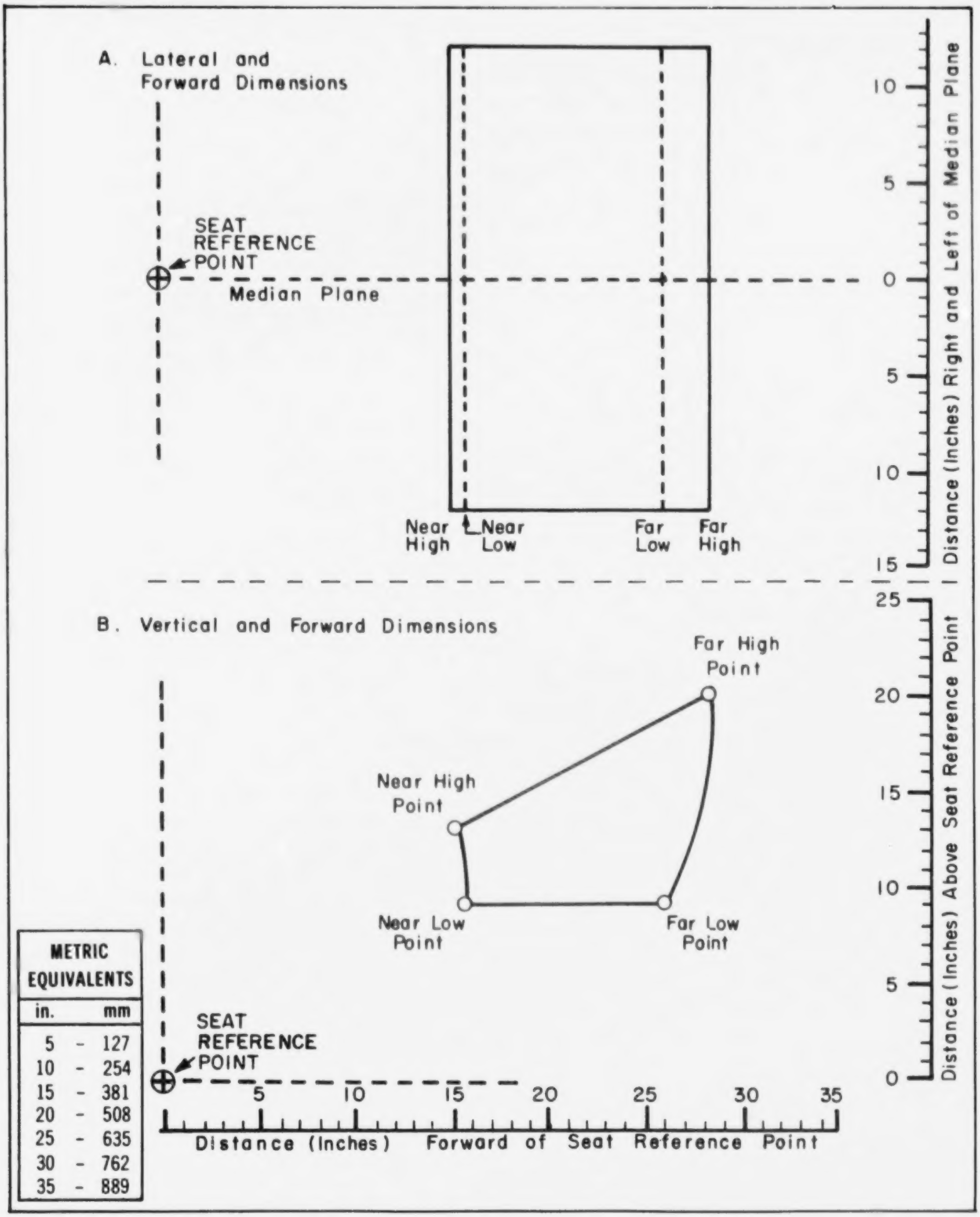
4.2 General Requirements

The placement of controls within the operator's workspace should be based on their frequency of use, criticality, and adjustment precision. The controls that are used most frequently and the controls that must be manipulated with the greatest speed and accuracy are considered to be primary and should be given the highest priority location on the control panel. Critical or emergency controls that are used to prevent personal injury and/or equipment destruction should be assigned a high priority location along with the primary controls. Secondary controls are those that are used less frequently, require only gross adjustment, and are less important than primary and emergency controls. Secondary controls may be placed in positions of lower priority unless they are used in conjunction with primary controls and displays. Nonemergency controls that are used rarely or not at all during normal equipment operation may be located on the outer areas of the control panel or behind hinged access covers. Equipment setup controls, or calibration and adjustment controls that are used infrequently or only prior to the use of the control console by the operator, should be assigned the lowest priority location.

4.3 Primary Controls

a. IOS Design Recommendation

Primary controls should be placed in the optimum manual space, which is shown in Figure 4-1. The dimensions provided in the figure are associated with a vertical backrest at a 0° tilt. Because the optimum space is dependent on the angle of the backrest, the space becomes smaller as the seat is rotated backward and a constant angle is maintained between the seat pan and backrest. The dimensions of the optimum space should be adjusted in accordance with Table 4-1 when the backrest is rotated backward.


A. Lateral and Forward Dimensions
SEAT REFERENCE POINT
Median Plane
Near High
Near Low
Far Low
Far High
10
5
0
5
10
15
Distance (Inches) Right and Left of Median Plane
B. Vertical and Forward Dimensions
Far High Point
Near High Point
Near Low Point
Far Low Point
SEAT REFERENCE POINT
25
20
15
10
5
0
Distance (Inches) Above Seat Reference Point
5
10
15
20
25
30
35
Distance (Inches) Forward of Seat Reference Point

METRIC EQUIVALENTS

in.		mm
5	-	127
10	-	254
15	-	381
20	-	508
25	-	635
30	-	762
35	-	889

Figure 4-1. Dimensions of Optimum Manual Space for Seated Operations. (From AFSC DH 1-3, 1980.)

Table 4-1. Dimensions of Optimum Manual Space for Seated Operations (From AFSC DH 1-3, 1980.)

Angle of Backrest	Near low point Forward of SRP[a]	Near low point Above SRP	Near high point Forward of SRP	Near high point Above SRP	Far low point Forward of SRP	Far low point Above SRP	Far high point Forward of SRP	Far high point Above SRP
0	393.7	228.6	381.0	330.2	660.4	228.6	723.9	508.0
10	355.6	228.6	342.9	330.2	558.8	228.6	635.0	520.7
20	317.5	228.6	304.8	330.2	469.9	228.6	546.1	520.7
30	279.4	215.9	266.7	304.8	381.0	215.9	457.2	495.3
40	241.3	190.5	228.6	279.4	304.8	190.5	368.3	457.2
50	215.9	165.1	203.2	254.0	254.0	165.1	292.1	406.4
60	190.5	139.7	177.8	228.6	190.5	139.7	228.6	342.9

Note. Values given in millimeters.

[a] Seat reference point (SRP)

The placement of controls on the operator's control console should conform to the following design principles:

1. Primary controls should be located between the operator's shoulder level and waist level.

2. Controls should not be located so that the simultaneous operation of two or more controls requires the operator to cross or interchange hands.

3. Frequently used controls should be grouped together unless there are overriding reasons for separating them.

4. Frequently used controls and controls requiring precise adjustment should be positioned for right-hand operation.

5. Controls should be located within a comfortable arm reach distance of the operator.

6. Controls should be located where the user can see them regardless of the viewing angle.

b. References: Requirements

1. AFSC DH 1-3 (1980): Primary controls should be assigned to the most favorable position with respect to ease of reaching and right-hand operation. The controls should be arranged for optimum distribution of loads between the hands, but the precise adjustment functions should be assigned mainly to the right hand. If the primary controls are to be used by more than one operator, duplicate controls should be provided whenever possible; otherwise, the controls should be centered between the operators. When a control is to be operated with one particular hand, it should be optimally located for that hand; when either hand may be used, the control should be centered. In general, primary controls should be positioned as follows:

(a) Close to the normal working position.
(b) Within a comfortable arm reach distance.
(c) Within 304.8 mm of the center of the control console.
(d) In line with the plane of the arm when controls are off-center.
(e) Between the operator's elbow and shoulder height.
(f) Not more than 609.6 mm from the operator's applicable arm.
(g) So that the simultaneous operation of two or more controls does not require crossing or interchanging arms.

The preferred location for primary controls, including the controls which require precise adjustment, is within the optimum manual space. The dimensions of the optimum manual space are illustrated in Figure 4-1 for a vertical backrest with 0° inclination. The seat reference point (SRP) is defined as the point where the midlines of the seat and backrest intersect. The height of the SRP is approximately 431.8 to 457.2 mm for a seated operator with the feet on the floor. At the Near Low Point in the figure, the operator's elbows are next to the body, with the forearms horizontal. At the Near High Point, the operator's elbows are next to the body, with the forearms flexed upward about the elbow at a 15° angle. The Far High Point is the outer limit of the operator's reach when the arms are extended horizontally from the shoulders. The Far Low Point is the maximum obtainable reach when the operator's arms are extended and lowered until the hands are at the level of the elbow in the Near Low Point position.

The optimum manual space is dependent on the angle of the backrest. As the seat is rotated backward with a constant angle maintained between the seat pan and backrest, the optimum space becomes smaller because the upper parts of the legs will tend to block portions of the control space. The dimensions of the space for seated operators at various backrest angles are provided in Table 4-1. The available space can be increased by lowering the front edge of the seat pan. The angle between the seat and backrest, however, should not exceed a maximum of 120°.

2. MIL-HDBK-759A (1981): Controls that must be operated frequently or are critical should be placed in the optimum manual space (Figure 4-2) to provide rapid and accurate identification, reaching, and operation. The following design principles should be used in arranging controls on the control panels:

(a) Primary controls should be located between the operator's shoulder level and waist level.

(b) Controls should not be located such that the simultaneous operation of two controls necessitates crossing or interchanging the operator's hands.

(c) Controls that are operated frequently should be located to the left front or right front of the operator.

(d) Controls that are frequently used should be grouped together unless there are overriding reasons for separating them.

(e) Frequently used controls should be located for right-hand operation.

(f) Controls that are frequently used should be located within a radius of 400 mm from the normal working position.

(g) Controls should be located where the user can see them regardless of the viewing angle.

(h) Controls requiring fine adjustments should be located closer to the operator's line of sight than gross-adjustment controls.

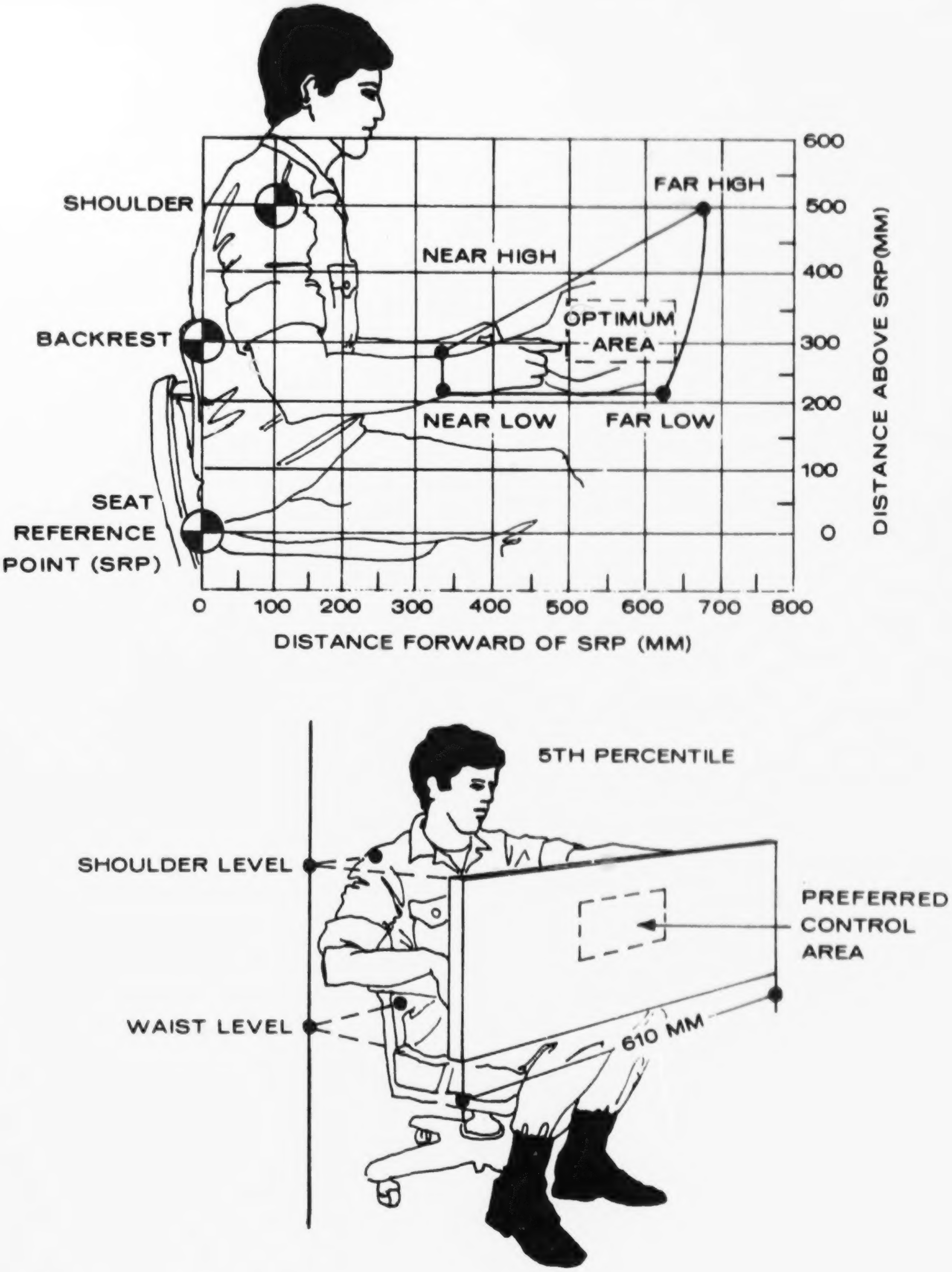

SHOULDER
BACKREST
SEAT
REFERENCE
POINT (SRP)
FAR HIGH
NEAR HIGH
OPTIMUM
AREA
NEAR LOW
FAR LOW
600
500
400
300
200
100
0
DISTANCE ABOVE SRP(MM)
0
100
200
300
400
500
600
700
800
DISTANCE FORWARD OF SRP (MM)
5TH PERCENTILE
SHOULDER LEVEL
WAIST LEVEL
PREFERRED
CONTROL
AREA
610 MM

Figure 4-2. Seated Optimum Manual Control Space. (From MIL-HDBK-759A, 1981.)

3. MIL-STD-1472C (1981): For seated operations, controls that require precise or frequent operation should be mounted between 200 and 740 mm above the sitting surface.

4. Woodson (1981): Frequently used adjustment controls should be positioned about at the operator's elbow level. Finger joysticks or roller-ball controllers should be placed nearer the back edge of the desk top, not close to the outer edge, to provide a resting area for the operator's arms. Controls that are used infrequently can be located in lower priority positions, but they should not be detached from related functional monitoring areas.

4.4 Secondary Controls

a. IOS Design Recommendation

The preferred location of secondary controls is on the frontal surface of the control console, as close as possible to the optimum control area. For seated operations, the placement of controls should conform to the guidelines presented in Figure 4-3. In the figure, the preferred surface areas and limits are provided for (a) primary controls, (b) emergency controls and precise-adjustment secondary controls, and (c) other secondary controls. The maximum flat surface area for secondary controls is also provided.

The principles that should be applied in the placement of secondary controls are as follows:

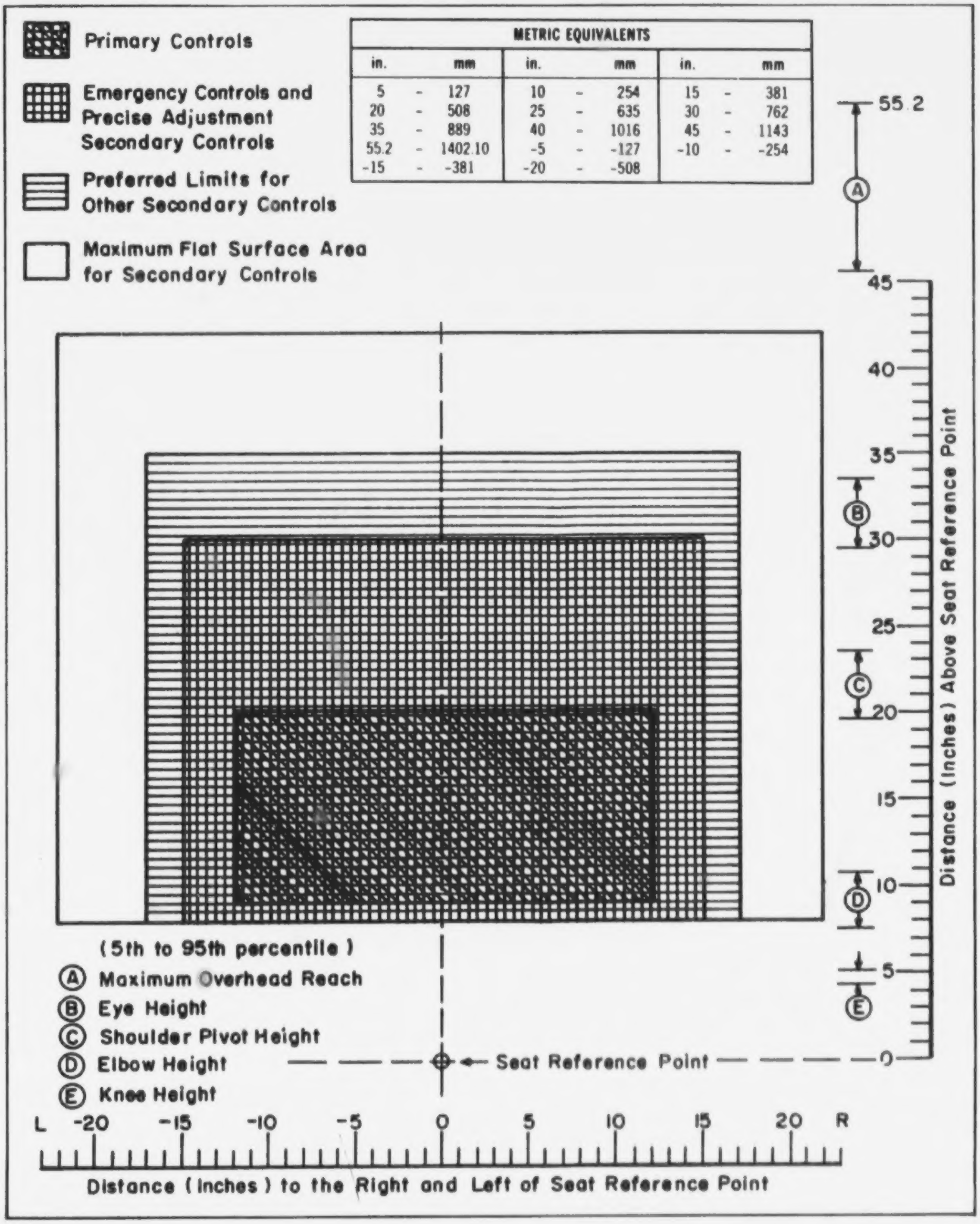
1. All controls should be placed within the maximum reach distance of the operators.

2. Controls that require manipulation while the operator is monitoring a display should be located near the display and directly below it.

3. Controls may be located above or to the right and left of the operator, but they should be within 95° of the median plane. Controls should not be placed on overhead panels or directly above the operator's position.

4. Controls that the operator must operate without seeing them (i.e., blind reaching) should be located directly in front of the operator or just above shoulder level.

5. Control panels should be contoured either vertically or horizontally within the operator's reach envelope when additional panel space is required for controls.



Primary Controls
Emergency Controls and Precise Adjustment Secondary Controls
Preferred Limits for Other Secondary Controls
Maximum Flat Surface Area for Secondary Controls
55.2
Ⓐ
45
40
35
Ⓑ
30
25
Ⓒ
20
15
Ⓓ
10
5
Ⓔ
0
Distance (Inches) Above Seat Reference Point
(5th to 95th percentile)
Ⓐ Maximum Overhead Reach
Ⓑ Eye Height
Ⓒ Shoulder Pivot Height
Ⓓ Elbow Height
Ⓔ Knee Height
Seat Reference Point
L -20 -15 -10 -5 0 5 10 15 20 R
Distance (inches) to the Right and Left of Seat Reference Point

METRIC EQUIVALENTS

in.		mm	in.		mm	in.		mm
5	-	127	10	-	254	15	-	381
20	-	508	25	-	635	30	-	762
35	-	889	40	-	1016	45	-	1143
55.2	-	1402.10	-5	-	-127	-10	-	-254
-15	-	-381	-20	-	-508			

Figure 4-3. Preferred Surface Areas and Limits for Manual Controls. (From AFSC DH 1-3, 1980.)

b. References: Requirements

1. AFSC DH 1-3 (1980): Secondary controls may be placed in positions of lower priority unless they are used in conjunction with a primary control or display. The controls may be located above or to the right or left of the operator, but they should be within 95° of the operator's median plane. Controls should not be placed on overhead panels or directly above the operator's working position. If the operator cannot see the controls that are to be operated (i.e., blind reaching), the controls should be located directly in front of the operator, if space permits, or just above shoulder level. Controls to be used by two operators should be centered between the two when equally important to both. The controls should be placed closer to the operator who requires the greatest use of them.

The preferred location of secondary controls is on the frontal surface of the control console, as close as possible to the optimum control area. For seated operations, the controls should be located as shown in Figure 4-3. Secondary controls requiring precise adjustment should be located between 203.2 and 762 mm above the sitting surface and within a span of 381 mm on either side of the median plane. The preferred location for other secondary controls on the console is between 203.2 and 889 mm above the sitting surface and within a span of 863.6 mm. The maximum secondary manual control space for seated operators is 203.2 to 1066.8 mm above the sitting surface and within a span of 1117.6 mm. The control panels should be contoured either vertically or horizontally within the reach envelope of the operator if additional panel space is required.

2. MIL-HDBK-759A (1981): The principles that should be adhered to in the arrangement of console controls are as follows:

(a) Occasionally used controls should be positioned within a radius of 500 mm from the operator's normal working position.

(b) Infrequently used controls should be within a radius of 700 mm.

(c) All controls should be placed within the maximum reach distance of the seated operator.

(d) Controls that must be manipulated while the operator is simultaneously monitoring a display should be placed close to and directly below that display.

(e) Infrequently used controls should be placed to one side and covered, if necessary, to prevent inadvertent activation.

(f) Controls that are used occasionally may be mounted behind hinged doors or recessed to reduce distraction and prevent the possibility of inadvertent activation.

(g) If the controls must be placed where the operator has to locate them without seeing them because of space constraints, the following operator error tendencies should be considered in positioning the controls:

   (1) Operators tend to reach too low for controls placed above shoulder level.

   (2) Operators tend to reach too far to the rear for controls placed on either side of the operator.

   (3) Operators tend to reach too high for controls placed below shoulder level.

(h) Groups of controls should be placed, insofar as possible, so that these error tendencies will not cause injuries, damage to equipment, or incorrect operation.

3. MIL-STD-1472C (1981): All controls used in the normal operation of the equipment and mounted on a vertical surface should be located from 200 to 860 mm above the sitting surface.

4.5 Emergency Controls

a. IOS Design Recommendation

Emergency controls should be given a high priority location on the control console along with primary controls even though emergency controls may be manipulated infrequently. They should be placed in the preferred area where they will be readily visible and accessible, regardless of the operator's position. Emergency controls should be separated from other controls used in normal operations whenever possible. If the controls would be inaccessible or poorly located, however, as a consequence of being physically separated, the normal controls should be provided with an emergency mode or special operating position, such as a detent position, an additional force, or an emergency release.

Emergency controls that are associated with extremely critical functions (i.e., the prevention of personal injury or equipment destruction) should be located within 15° laterally on either side of the operator's normal line of sight and within 30° above and below the normal sight line.

b. Reference

The recommendations for the placement of emergency controls were drawn from AFSC DH 1-3 (1980).

5. WORKSTATION DESIGN

5.1 Introduction

This section provides the dimensions that should be used in IOS designs to ensure the proper clearances for the expected population of operators, the visibility of the displays, and the accessibility of the controls. Use of the design guidelines will permit the operator to enter and exit the IOS area safely and with ease and to comfortably sit at and operate the IOS for extended periods of time. The recommended IOS dimensions vary as a function of the amount and types of equipment the IOS must contain and the body sizes of the anticipated users. Design guidelines are presented for high- and low-profile workstations with and without vision over the top, horizontal wraparound and vertical workstation configurations, workstation clearances for male and female operators, workstations for continuous keyboard operations, and movable workstations.

5.2 General Requirements

a. IOS Design Recommendation

The guidelines presented in Figure 5-1 should be used in the design of an IOS to provide a standardized configuration. The dimensions shown are based on male anthropometric data. Consequently, they may have to be adjusted if females are expected to use the IOS or if the IOS is being designed for a select group of users who are not representative of the general population. An IOS should be designed to conveniently accommodate the 5th through 95th percentile body sizes of the users. It is advisable to construct and evaluate a mockup of the preliminary design using a representative sample of users. Adjustments can be made and evaluated with the mockup as required to finalize the IOS design.

b. Reference

Figure 5-1 is from Van Cott and Kinkade (1972).

5.3 Special-Purpose Workstation Designs

There is no single workstation configuration that is applicable to all IOS design situations. Innovative and specialized designs are frequently required, such as when a large amount of electronic equipment and components must be stored in the IOS, when several CRTs and a variety of indicators and controls are used, and when the IOS must be designed to accommodate female personnel. Guidelines have been developed for these special-purpose applications and should be adhered to closely to derive the benefits and economies inherent in standardized designs.

5.3.1 Standard Workstation Variations

a. IOS Design Recommendation

A high-profile workstation should be used when a large amount of space is required to store electronic and other equipment; otherwise, a

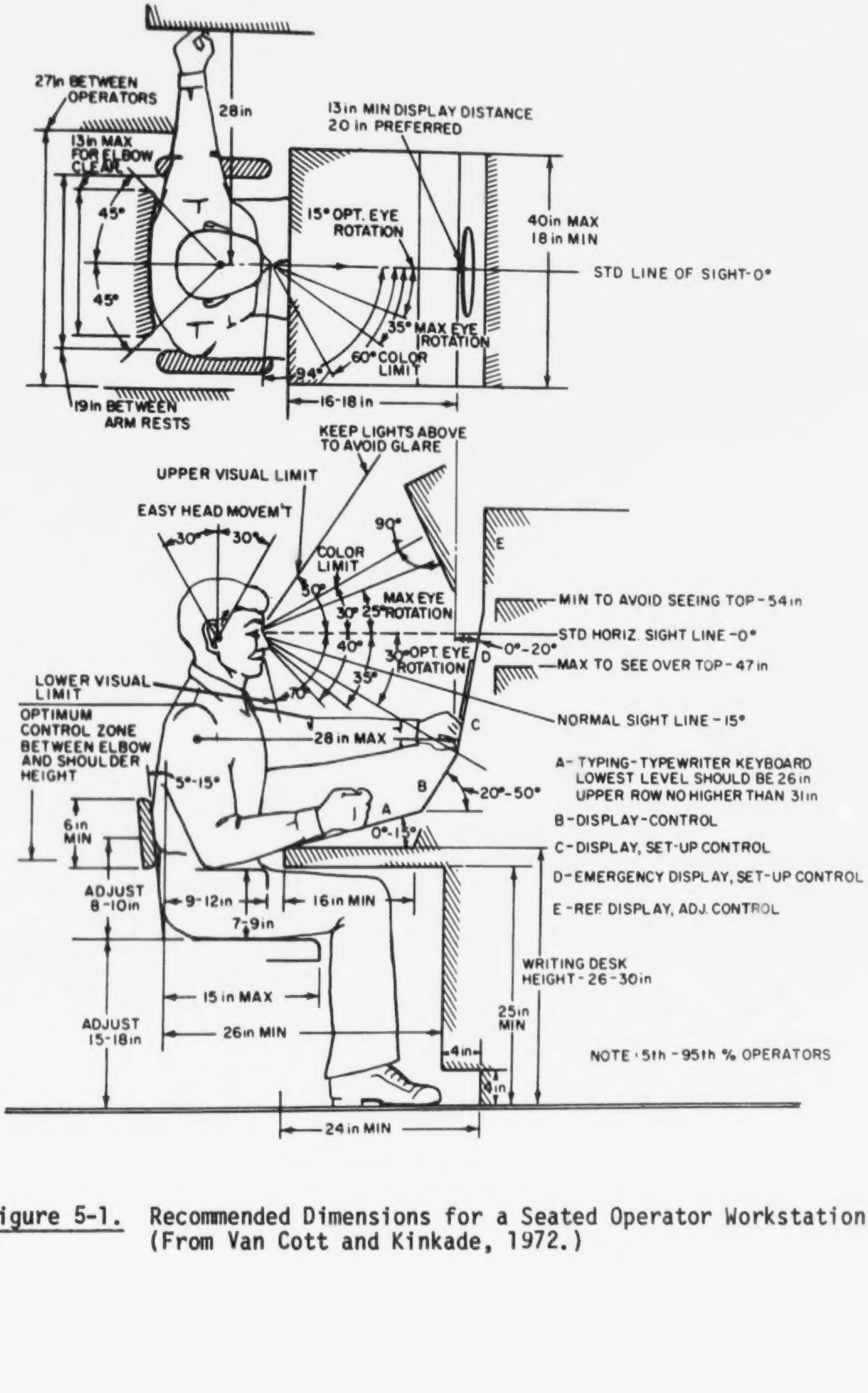

27in BETWEEN OPERATORS
28in
13in MIN DISPLAY DISTANCE
20 in PREFERRED
13in MAX FOR ELBOW CLEAR
45°
45°
15° OPT. EYE ROTATION
40in MAX
18in MIN
STD LINE OF SIGHT-0°
35° MAX EYE ROTATION
60° COLOR LIMIT
94°
16-18 in
19in BETWEEN ARM RESTS
KEEP LIGHTS ABOVE TO AVOID GLARE
UPPER VISUAL LIMIT
EASY HEAD MOVEM'T
30°
30°
90°
E
COLOR LIMIT
50°
MAX EYE ROTATION
30°
25°
MIN TO AVOID SEEING TOP-54in
STD HORIZ. SIGHT LINE-0°
40°
0°-20°
30° OPT. EYE ROTATION
D
MAX TO SEE OVER TOP-47in
LOWER VISUAL LIMIT
70°
35°
NORMAL SIGHT LINE-15°
OPTIMUM CONTROL ZONE BETWEEN ELBOW AND SHOULDER HEIGHT
28 in MAX
C
A-TYPING-TYPEWRITER KEYBOARD LOWEST LEVEL SHOULD BE 26in UPPER ROW NO HIGHER THAN 31in
5°-15°
B
20°-50°
6in MIN
A
0°-15°
B-DISPLAY-CONTROL
C-DISPLAY, SET-UP CONTROL
D-EMERGENCY DISPLAY, SET-UP CONTROL
ADJUST 8-10in
9-12in
16in MIN
E-REF. DISPLAY, ADJ. CONTROL
7-9in
WRITING DESK HEIGHT-26-30in
15 in MAX
25in MIN
ADJUST 15-18in
26in MIN
4in
NOTE: 5th-95th % OPERATORS
4in
24in MIN

Figure 5-1. Recommended Dimensions for a Seated Operator Workstation. (From Van Cott and Kinkade, 1972.)

low-profile station is preferred. In Table 5-1, the dimensions are provided for a high- and low-profile workstation for a single seated operator when vision over the top is required and when there is no requirement for vision over the top. The dimensions appearing in the table are based on male anthropometric data. A key for the tabular data is presented in Figure 5-2.

b. References

The recommended workstation dimensions were adapted from Kennedy and Bates (1965), MIL-HDBK-759A (1981), and MIL-STD-1472C (1981).

5.3.2 Horizontal, Wraparound Workstation

a. IOS Design Recommendation

A segmented, wraparound workstation configuration (Figure 5-3) should be provided when the preferred panel space for a single seated user requires a panel width larger than 1.12 m. All controls should be placed within the reach of the 5th percentile stationary operator. A design for a horizontal, wraparound workstation should conform to the guidelines provided below:

1. Panel Angle: The left and right segments should be angled relative to the center panel such that the displays are perpendicular to the observer's line of sight and that the controls can be reached by the 5th percentile stationary user.

2. Workstation Dimensions: When vision over the top is required, thereby limiting vertical space, the center panel should not exceed 1.12 m in width; and the left and right segments should not be wider than 610 mm. When vision over the top is not required, the total workstation height may exceed the height of the seat by more than 685 mm; however, the center panel should not exceed 860 mm, and the left and right segments should be no wider than 610 mm.

3. Viewing Angle: The total viewing angle required from left to right should not be greater than 190°. If possible, this angle should be reduced through the appropriate control/display layout.

b. References

The design guidelines for a horizontal, wraparound workstation are from MIL-HDBK-759A (1981) and MIL-STD-1472C (1981).

5.3.3 Vertically Oriented Workstation

a. IOS Design Recommendation

When vision over the top of the workstation is not required and when lateral space is limited, a workstation for a seated operator should be separated into three panels and vertically stacked as shown in Figure 5-4. The panel surfaces should be perpendicular to the viewer's line of sight with little or no head movement. The height of the center panel should not be greater than 530 mm, and the center of this panel should be 800 mm above the SRP.

Table 5-1. Standard Workstation Variations (Composite data from MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

KEY		Low-profile workstation		High-profile workstation	
		With vision over top	Without vision over top	With vision over top	Without vision over top
A	Maximum height from floor	1.170 - 1.210 m	1.310 m	1.435 - 1.470 m	1.570 m
B	Recommended vertical panel size	520 - 560 mm	660 mm	520 - 560 mm	660 mm
C	Writing surface height from floor	650 mm	650 mm	910 mm	910 mm
D	Seat height from floor at midrange of adjustment (G)	435 - 460 mm	435 - 460 mm	695 - 725 mm	695 - 720 mm
E	Minimum knee clearance	460 mm	460 mm	460 mm	460 mm
F	Footrest from sitting surface - required when "D" exceeds 460 mm	460 mm	460 mm	460 mm	460 mm
G	Vertical seat adjustment	125 - 150 mm	125 - 150 mm	125 - 150 mm	125 - 150 mm
H	Minimum thigh clearance at midrange of "G"	165 - 190 mm	165 - 190 mm	165 - 190 mm	165 - 190 mm
I	Writing surface depth	400 mm	400 mm	400 mm	400 mm
J	Minimum shelf depth	100 mm	100 mm	100 mm	100 mm
K	Eye line to front panel distance	400 mm	400 mm	400 mm	400 mm
Not Shown	Maximum workstation width	1.120 m	910 m	1.120 m	910 m

Notes. 1. All dimensions based on male anthropometric data.
2. A writing surface thickness of 25 mm is assumed. Proper adjustments should be made for other thicknesses.

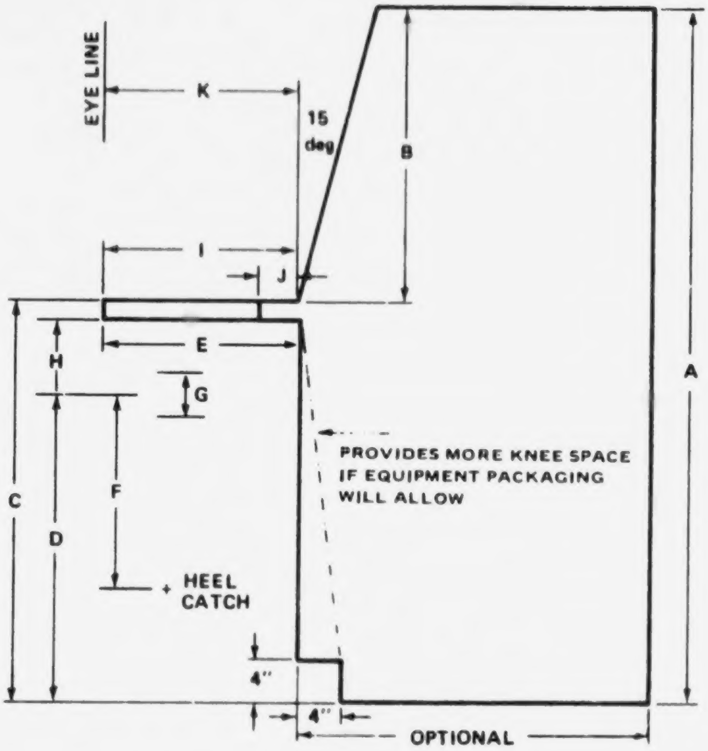

EYE LINE
K
15 deg
B
I
J
E
H
G
A
PROVIDES MORE KNEE SPACE IF EQUIPMENT PACKAGING WILL ALLOW
C
F
D
HEEL CATCH
4"
4"
OPTIONAL

Figure 5-2. Standard Workstation Configuration and Dimensions Key. (From MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

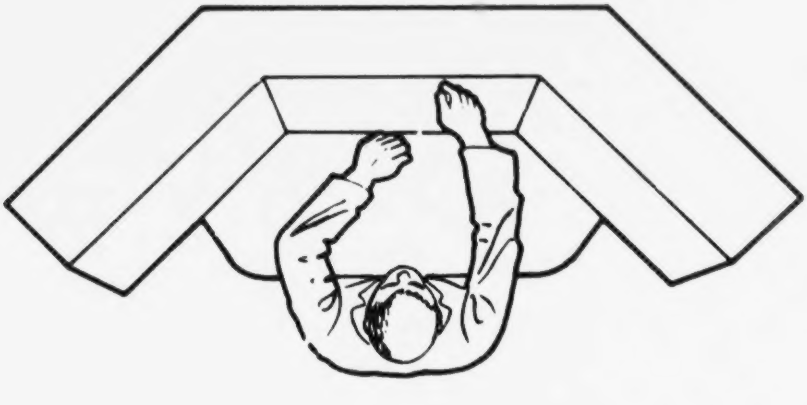


Figure 5-3. Horizontal Wraparound Workstation Configuration. (From (MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

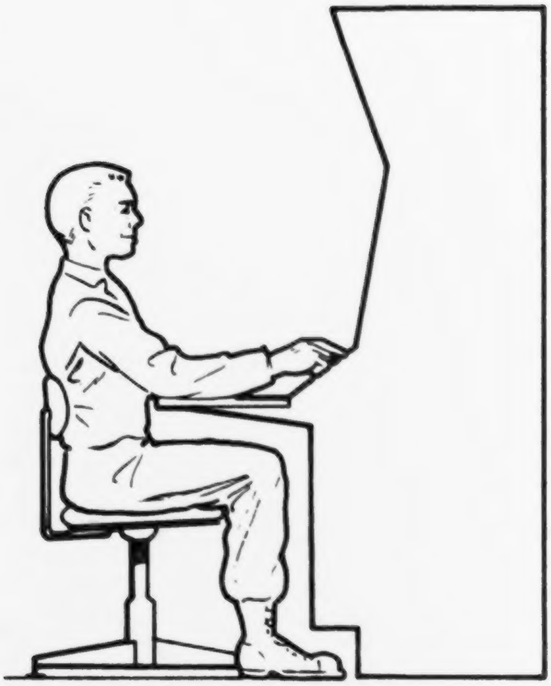


Figure 5-4. Vertically Oriented Workstation Configuration. (From MIL-HDBK-759A, 1981, and MIL-STD-1472C, 1981.)

b. References

These design recommendations are from MIL-HDBK-759A (1981) and MIL-STD-1472C (1981).

5.3.4 Workstation Design for Female Operators

a. IOS Design Recommendation

The guidelines provided in Figure 5-5 should be used in the design of workstations for females. Reach distances for the 5th and 95th percentile females are illustrated in Figure 5-6. (Note: The workstation depicted in Figure 5-5 was designed for microwelding in the machine shop of an aircraft manufacturer, but the suggested dimensions have application in IOS design.)

b. Reference

These design guidelines are from Rosenthal (1973).

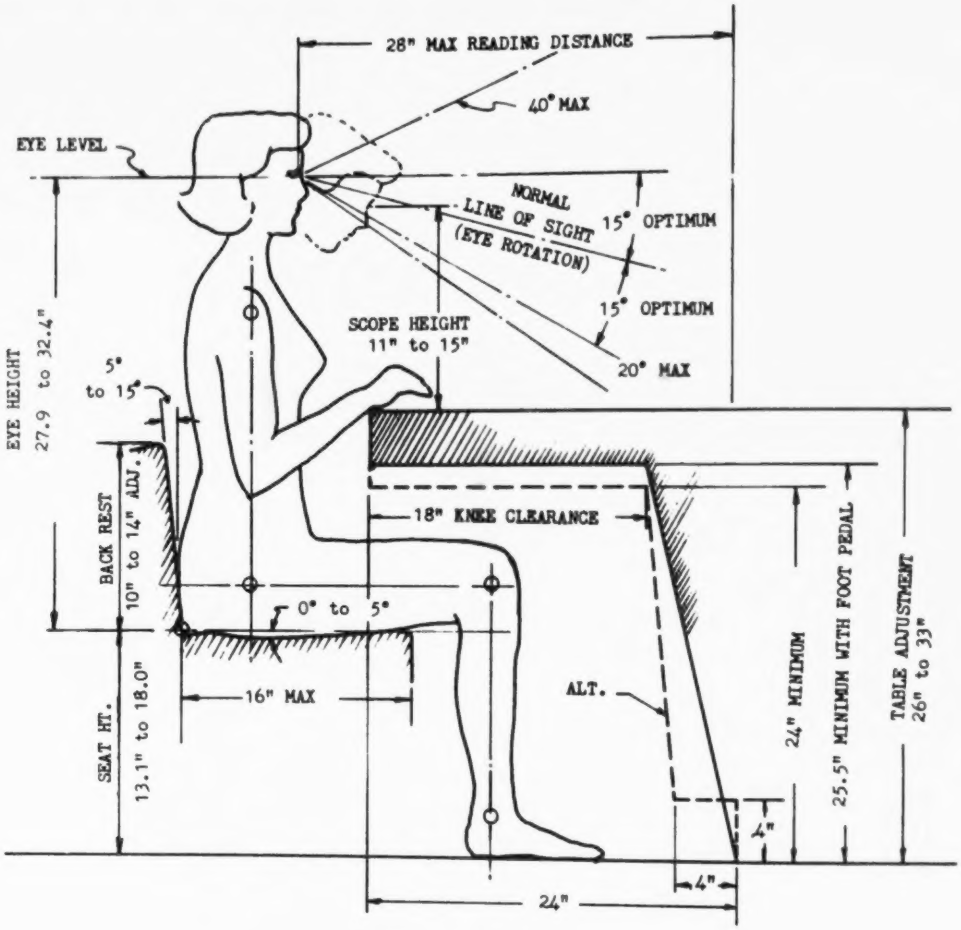

28" MAX READING DISTANCE
40° MAX
EYE LEVEL
NORMAL LINE OF SIGHT (EYE ROTATION)
15° OPTIMUM
15° OPTIMUM
SCOPE HEIGHT 11" to 15"
20° MAX
EYE HEIGHT 27.9 to 32.4"
5° to 15°
BACK REST 10" to 14" ADJ.
0° to 5°
18" KNEE CLEARANCE
16" MAX
ALT.
SEAT HT. 13.1" to 18.0"
24" MINIMUM
25.5" MINIMUM WITH FOOT PEDAL
TABLE ADJUSTMENT 26" to 33"
4"
4"
24"

Figure 5-5. Workstation Design for Female Operators. (From Human Factors, 1973, 15[2], p.141. Copyright 1973, by the Human Factors Society, Inc. and reproduced by permission.)

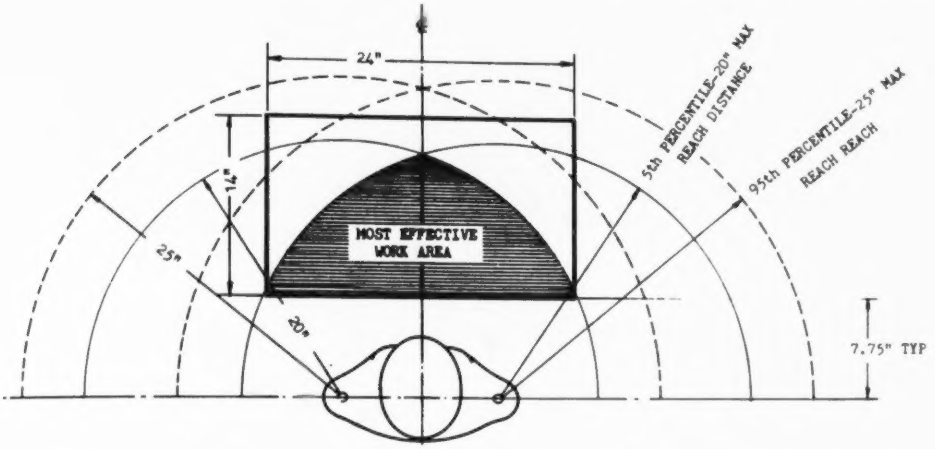

24"
14"
25"
20"
MOST EFFECTIVE WORK AREA
5th PERCENTILE-20" MAX REACH DISTANCE
95th PERCENTILE-25" MAX REACH REACH
7.75" TYP

Figure 5-6. Maximum Horizontal Reach Distances for Female Operators. (From Human Factors, 1973, 15[2], p.141. Copyright 1973, by the Human Factors Society, Inc. and reproduced by permission.)

5.3.5 Workstation Design for Continuous Keyboard Operations

a. IOS Design Recommendation

Where personnel are required to continuously operate a keyboard and simultaneously monitor a CRT display, such as in text and data entry tasks, the guidelines presented in Figure 5-7 should be considered in the design of the workstation. The dimensions provided in the figure correspond to the 5 percentile lower limit for the female population and the 95 percentile upper limit for the male population. The primary factors in the design of workstations for continuous keyboard operations are as follows:

1. Working Level: The working level refers to the distance between the underside of the thighs and the palms of the hand. It is based on an operator seated in a nearly upright position with the hands and forearms extended 90° horizontally from the vertical plane of the torso. Sizing of the working level is crucial in workstation design to ensure that sufficient knee clearance is provided and that the hands and arms are favorably positioned when using the keyboard. The working level should be between 220 and 250 mm.

2. Desk Height: The height of the desktop should be between 720 and 750 mm, with a minimum leg room height between 650 and 690 mm. Where the keyboard is detached from the display screen, the distance between the home row of keys on the keyboard and the floor should be between 720 and 750 mm.

3. Chair, Seating Height, and Back Support: The chair height should be adjustable so that keyboard operations can be performed in an upright posture with the forearms extended approximately horizontally. A chair with a backrest is required for pelvic and lumbar support. Both the height and angle of the backrest should be adjustable, with the surface contacting the operator's back curving smoothly outward. The seat should be made of rough textured and flexible materials, and it should be constructed in a manner that allows air circulation over the operator's skin surface. The front edge of the seat should be curved downward to relieve pressure on the thighs.

4. Footrest: The operator's feet should rest flat on the floor comfortably, and the thighs should be horizontal. If the operator has to stretch to achieve this posture, a footrest should be provided. It should be adjustable both in height (0 to 50 mm) and inclination (10° to 15°). If possible, it should be secured to prevent sliding.

5. Document Holder: The design requirements for the type and position of the manuscript holder vary according to the operator's task and the frequency of manuscript change, as specified in Table 5-2. A document holder that could be placed on either side of the CRT terminal would be desirable to accommodate both left- and right-handed operators.

6. Keyboard Placement: The distance between the back row of keys on the workstation keyboard and the front edge of the desk should not exceed 400 mm. In general, the keyboard should always be within easy reach of the user in the normal operating position. If space permits, an area in front of the keyboard with a depth of approximately 60 mm for resting the hands is recommended.

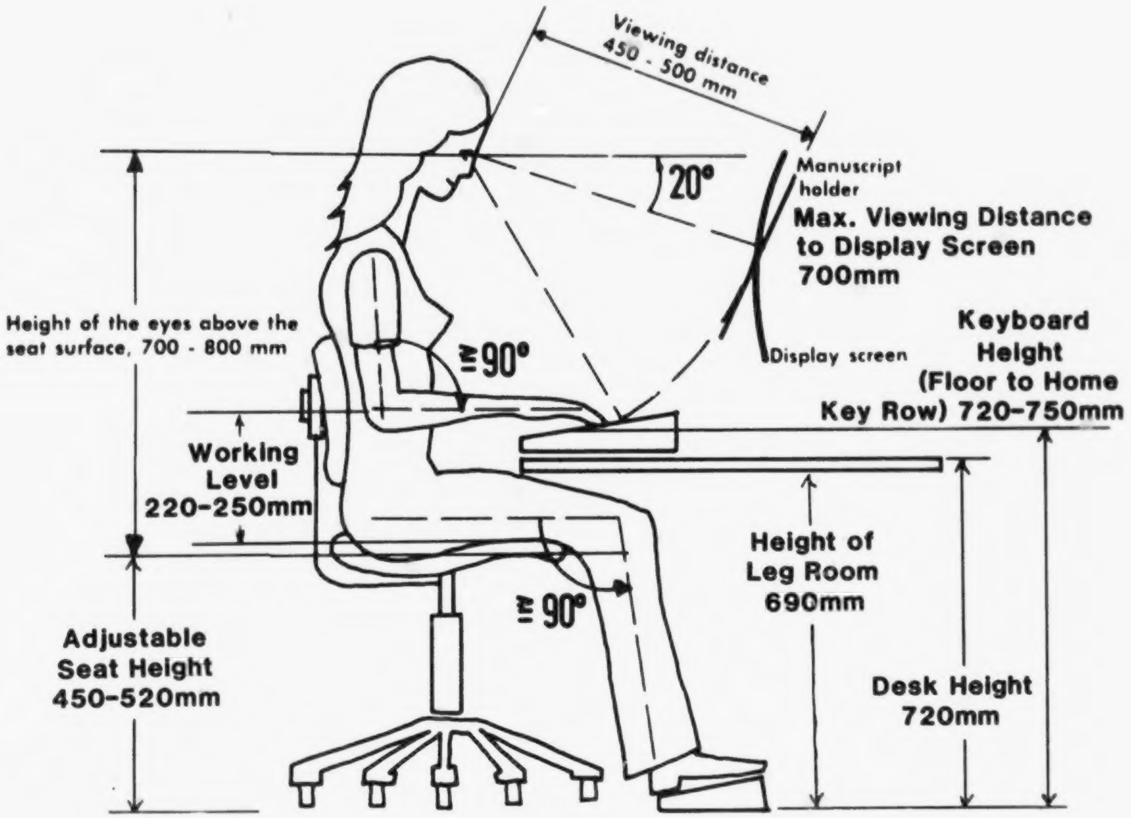

Viewing distance
450 - 500 mm
20°
Manuscript holder
Max. Viewing Distance to Display Screen 700mm
Height of the eyes above the seat surface, 700 - 800 mm
≧90°
Display screen
Keyboard Height (Floor to Home Key Row) 720-750mm
Working Level 220-250mm
Height of Leg Room 690mm
≧90°
Adjustable Seat Height 450-520mm
Desk Height 720mm

Figure 5-7. Workstation Design Guidelines for Continuous Keyboard Operations. (From Visual Display Terminals [p. 169] by A. Cakir, D.J. Hart, and T.F.M. Stewart, 1980, Chichester, Sussex, England: John Wiley & Sons, Ltd. Copyright 1980 by John Wiley & Sons, Ltd. reprinted by permission.)

b. Reference

The workstation design guidelines for continuous keyboard operations are from Cakir et al. (1980).

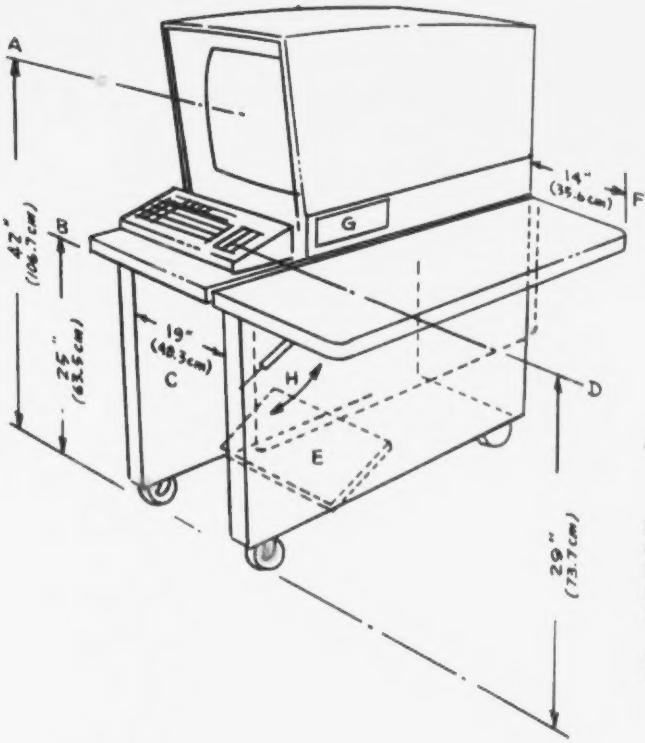
5.3.6 Workstation Design for Movable, Independent Modules

a. IOS Design Recommendation

The recommended dimensions for independent and movable workstation modules are provided in Figure 5-8. The use of a movable workstation introduces two potential problems concerning the cabling. First, the cables should be sufficiently long that the module can be moved to wherever it is needed. Second, the cables should be located where they will not be hazardous to personnel or interfere with the movement of emergency equipment.

Table 5-2. Design Guidelines for Manuscript Holders (From *Visual Display Terminals* (p. 168) by A. Cakir, D.J. Hart, and T.F.M. Stewart, 1980, Chichester, Sussex, England: John Wiley & Sons Ltd. Copyright 1980 by John Wiley & Sons, Ltd. Reprinted by permission.)

Task	Frequency of manuscript change	Type and position of manuscript holder
Pure copy entry, no manipulation	Seldom	Size: according to type of document Row marker: yes Position: to the left of the display screen, 20° angle
Copy entry with some manipulation (e.g., occasional notes)	Seldom	Size: as above Row marker: as above Position: to the right of the display screen
Pure copy entry, no manipulation	Frequent	Size: as above Row marker: preferably Position: to the left of the display screen, or between the keyboard and screen
Copy entry with some manipulation	Frequent	Size: as above Row marker: as above Position: to the right of the display screen
Pure copy entry, no manipulation (mostly numerical data)	Very frequent	Size: as above Row marker: no Position: to the left of the keyboard



A—The center of a vertically oriented CRT should be approximately as shown. Note that the case extends over the tube to minimize glare from overhead ambient light.
B—Vertical knee clearance minimum.
C—Lateral knee clearance minimum.
D—Center height of keyboard.
E—Footrest.
F—Minimum width for fold-down writing surface.
G—CRT controls (under cover).
H—Supporting bracket for fold-down desk. Casters with locks allow the unit to be moved around to fit the user's needs.

Figure 5-8. Workstation Dimensions for Movable, Independent Modules. (From Human Factors Design Handbook [p. 385] by W.E. Woodson, 1981, New York, NY: McGraw-Hill, Inc. Copyright 1981 by McGraw-Hill, Inc. Reprinted by permission.)

b. Reference

Figure 5-8 is from Woodson (1981).

6. WORKSTATION SEATING

6.1 Introduction

A properly designed seat will allow the operator to maintain good posture while using an IOS. Given an opportunity to develop and exercise good postural habits, operators will experience less physical fatigue and, consequently, will be able to perform their tasks more efficiently and for longer periods. A variety of seats that are based on laboratory ergonomic tests are currently available on the market, so there is essentially no requirement for the IOS designer to also design and construct the seating for operator personnel. The guidelines provided in this section on workstation seating should be used in the selection of seats for operator use in IOS applications.

6.2 General Requirements

The major dimensions of an adjustable chair for seated operations are illustrated in Figure 6-1, and the specific paragraphs dealing with these dimensions are identified in Table 6-1.

6.3 Seat Pan

6.3.1 Seat Pan Height

a. IOS Design Recommendation

The seat height of the chair should be adjustable. The range of adjustment should be between 380 and 535 mm, with increments not exceeding 25 mm. If an adjustable seat cannot be provided, consideration should be given to having two seats available for use: a short one and a tall one to accommodate operators of varying heights. Where one chair must accommodate a wide range of heights, the best compromise seat height is about 432 mm. The optimum seat height allows the thighs to be horizontal, the lower legs vertical, and the feet flat on the floor. The seat pan height should accommodate the 5th through 95th percentile users' popliteal heights (the vertical distance from the floor to the area of the leg immediately behind the knee).

b. References: Requirements

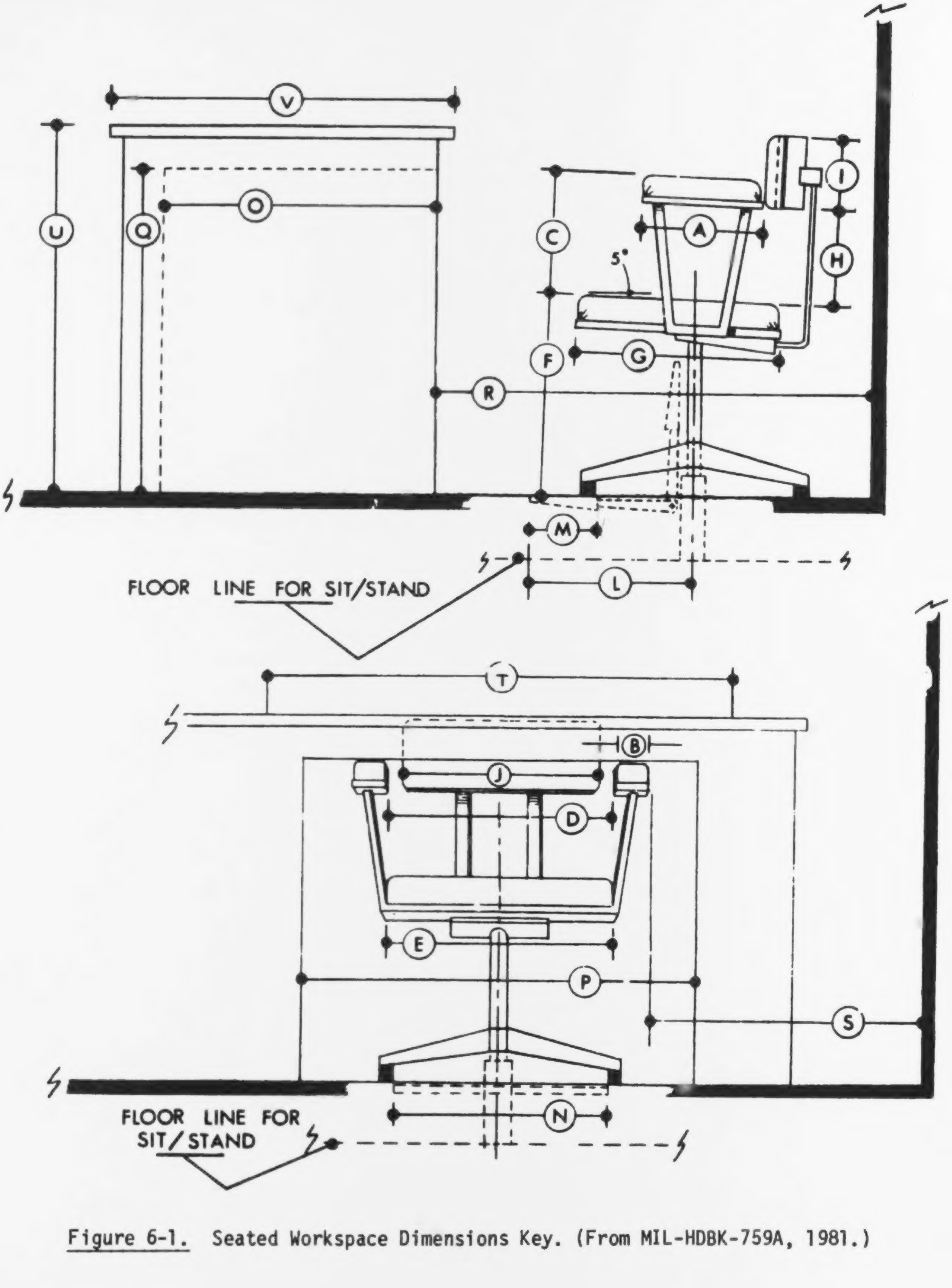
1. Ayoub and Halcomb (1976): Seat pan height should be slightly less than the occupant's popliteal height. The seat height should be adjustable to accommodate the popliteal heights of the smallest (e.g., 5th percentile) and the largest (e.g., 95th percentile) users.

2. Cakir et al. (1980): Chair height should be adjustable in the range of 450 to 520 mm. The height is optimum when the operator's feet are flat on the floor and the thighs are in a horizontal position.

3. IBM Corporation (1979): The operator should be able to adjust the seat height so that in the seated position the thighs are reasonably horizontal, the lower legs are vertical, and the feet are on the floor. A chair that is too high may induce pressure on the lower thighs. If the chair is too low, the pelvis will tend to rotate and the lower spine will curve outward.

4. MIL-HDBK-759A (1981): An adjustable seat height is preferred. For a fixed seat, the recommended height is 460 mm; for an adjustable seat, the range of adjustment should be 410 to 510 mm.

5. MIL-STD-1472C (1981): Seat height should be adjustable from 380 to 535 mm in increments not greater than 25 mm each.


V
U
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FLOOR LINE FOR SIT/STAND
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FLOOR LINE FOR SIT/STAND

Figure 6-1. Seated Workspace Dimensions Key. (From MIL-HDBK-759A, 1981.)

Table 6-1. Workstation Seating Dimensions

Dimensions			Paragraph
Chair			
Armrests:	A.	Length	6.5.1
	B.	Width	6.5.2
	C.	Height	6.5.3
	D.	Separation	6.5.4
Seat Pan:	E.	Width	6.3.2
	F.	Height	6.3.1
	G.	Depth	6.3.3
		(Slope)	6.3.4
		(Cushioning)	6.3.5
		(Shape)	6.3.6
Backrest:	H.	Space	6.4.3
	I.	Height	6.4.1
	J.	Width	6.4.2
		(Angle)	6.4.4
		(Shape)	6.4.5
Footrest	L.	From Center	(180 mm)
	M.	Width	6.6.2
	N.	Length	6.6.2
Work Space			
Kneespace	O.	Depth	5.2
	P.	Width	5.2
	Q.	Height	5.2
From Wall:	R.	Desk	(810 mm Min)
	S.	Armrest	(610 mm Min)
Work Surface:	T.	Width	5.2
	U.	Height	5.2
	V.	Depth	5.2

6. Woodson (1981): A seat pan height of about 17 in. (43.2 cm) at the leading edge is the best compromise for a wide range of male and female adults for normal seating. If the seat is higher than this, the legs of small personnel will not touch the floor. In fact, the recommended height is based on the general assumption that females will be wearing shoes with heels from 3.8 to 5.1 cm in height. Although a lower seat pan height would be desirable to accommodate very short-legged operators, long-legged operators would have difficulty getting out of the seat.

6.3.2 Seat Pan Width

a. IOS Design Recommendation

Seat pan width has only a minimum dimension, not a maximum. The largest hip breadth or the largest sitting or thigh breadth that must be accommodated should be used to determine seat width. Hip breadths for various user populations are provided in Section 7, Anthropometric Data. A 405- to 483-mm seat pan width is recommended.

b. References: Requirements

1. Ayoub and Halcomb (1976): Seat pan width has a minimum, but no maximum dimension. Seat pan width is based on the largest-sized user's hip breadth or the sitting or thigh breadth as measured at the widest part of the thighs in a sitting position. The seat pan may be 2 in. less than the largest (e.g., 95th percentile) hip breadth to be accommodated.

2. MIL-HDBK-759A (1981): A seat pan width of 405 mm is recommended.

3. Woodson (1981): The width of the seat should be approximately 48.3 cm to accommodate large-sized operators.

6.3.3 Seat Pan Depth

a. IOS Design Recommendation

Seat pan depth should be based on the buttock-to-popliteal length. If the seat depth is adjustable, the minimum depth should be based on the smallest length to be accommodated, and the maximum depth, on the largest. If the seat depth is to be nonadjustable, the smaller length should be used as the determining factor. A seat pan depth of 405 to 432 mm is recommended.

b. References: Requirements

1. Ayoub and Halcomb (1976): The seat depth should not be excessive because when smaller users are unable to lean against the backrest, they will tend to sit forward on the front part of the seat to avoid pressure on the back of the legs. If no adjustment for the seat depth is provided, the seat depth should be based on the smallest buttock-to-popliteal length to be accommodated. If the seat depth is adjustable,

the minimum and maximum seat depths should be based on the smallest and largest lengths to be provided for.

2. MIL-HDBK-759A (1981): A seat depth of 405 mm is recommended.

3. Woodson (1981): The length of the seat pan should be about 43.2 cm.

6.3.4 Seat Pan Slope

a. IOS Design Recommendation

The seat pan should be sloped rearward from 5° to 7°.

b. References: Requirements

1. Ayoub and Halcomb (1976): A seat pan that is generally horizontal and slightly concave will help keep the operator in the middle of the seat and prevent sliding. Additionally, a slight slope rearward will prevent the operator from sliding out of the seat. If the seat slope is adjustable, it is desirable to have it slope both above and below the horizontal.

2. MIL-HDBK-759A (1981): The seat should be tilted back from 5° to 7°.

3. Woodson (1981): The seat pan should be tilted back approximately 5°.

6.3.5 Chair Cushioning

a. IOS Design Recommendation

Rough-textured and flexible material should be used in preference to shiny and hard materials. Textured material will help stabilize the sitting position by providing greater friction to prevent the operator from sliding or slipping off, and a flexible material will help to distribute the pressure evenly over the seat and eliminate pressure spots. The covering should be perforated or ventilated to allow air circulation over the skin surface and minimize hotness or sweatiness. The seat cushioning should be neither too hard nor too soft, and deep cushions and/or springs should not be used.

b. References: Requirements

1. Ayoub and Halcomb (1976): Seat pan upholstery that is flat and stiff will reduce pressure on the buttocks and also allow posture changes. It should also provide ventilation to reduce sweating.

2. Cakir et al. (1980): The properties and design of the seat covering affect both the pressure distribution between the body and seat surface and the stability of the sitting position. For these two reasons, rough textured and flexible material is preferred over shiny and hard

material. Textured material helps stabilize the sitting position by providing greater friction, which prevents the operator from sliding or slipping off; and a flexible material helps to evenly distribute pressure over the seat and avoid pressure spots. The covering of the seat should also allow circulation of air over the operator's skin surface. Hard material should not be used for seat covering when prolonged sitting is required.

3. IBM Corporation (1979): If the surface of the seat is too hard, the pressure is concentrated, causing discomfort to the operator over time. If the seat is too soft, it may cause the operator to "float" and thus use extra muscle effort to maintain a given position. When occupied, a reasonably firm chair seat compresses about 2 cm.

4. MIL-HDBK-759A (1981): Chairs with cushioning should be used for operators who must be seated for more than an hour at a time or more than 20% of the time. For intermittent sitting, uncushioned stools or benches are permitted. Good seat cushions should have the following features:

(a) Flat, firm shape with enough softness to be deformed.

(b) Resilient material under the cushion to absorb shocks.

(c) Body weight support especially around the two bony points of the pelvis.

(d) Shaping to follow the inward curve of the lower back and relieve strain on the back muscles.

(e) Absence of pressure under the thighs.

(f) Perforated or ventilated material to prevent hotness or sweatiness.

(g) Shaping that allows the sitter to change positions.

5. MIL-STD-1472C (1981): When applicable, both the seat pan and backrest should be cushioned with at least 25 mm of compressible material and have a smooth surface.

6. Woodson (1981): Deep cushions, soft cushioning, and/or springs should not be used for either the seat pan or backrest.

6.3.6 Seat Pan Shape

a. IOS Design Recommendation

Generally speaking, no seat pan shaping is required. The front edge may be curved downward slightly to prevent it from causing excessive pressure on the thighs.

b. References: Requirements

1. Ayoub and Halcomb (1976): The seat pan should permit changing position and posture with ease, and the front should not cause excessive pressure on the thighs. Shaping of the seat pan is not recommended.

2. Cakir et al. (1980): The front edge of the seat should be curved downward to prevent it from cutting into the thighs in the sitting position.

3. IBM Corporation (1979): The chair should be shaped to facilitate frequent position changes, and place most of the pressure on the buttocks, not the thighs.

4. MIL-HDBK-759A (1981): Chair seats should have a flat shape.

5. Woodson (1981): Contoured seat pans and backrests should be avoided. Flat is preferred because no two people need the same contour. A contour in the wrong place is worse than none at all.

6.4 Backrest

6.4.1 Backrest Height

a. IOS Design Recommendation

Backrest height is dependent on the requirement for mobility of the shoulders and arms. A small-sized backrest of about 150 mm should be used when mobility is required, and a full-sized backrest of about 508 mm may be used when mobility is not required or required infrequently.

b. References: Requirements

1. Ayoub and Halcomb (1976): Backrest height is dependent on the requirement for mobility of the shoulders and arms. A small, kidney-shaped backrest should be used when mobility is required, and a full-sized backrest may be used when mobility is not required.

2. MIL-HDBK-759A (1981): The height of the backrest should be 380 mm.

3. Woodson (1981): The height of the seatback, measured from the seat pan, should be 50.8 cm so that the shoulder blades of even the tallest operator are supported.

6.4.2 Backrest Width

a. IOS Design Recommendation

A width of about 483 mm is recommended for full-sized seatbacks and about 405 mm for the small-sized backrests.

b. References: Requirements

1. Ayoub and Halcomb (1976): Backrest width is dependent on the requirement for shoulder and arm mobility. When mobility and turning are required, the width of the backrest should be less than the smallest bi-illiac crest width to be accommodated; when mobility is not required, the width should support the largest shoulders to be accommodated.

2. MIL-HDBK-759A (1981): The backrest should be 405 mm wide.

3. Woodson (1981): A 48.3-cm backrest is recommended.

6.4.3 Backrest Spacing

a. IOS Design Recommendation

If the seatback used is small sized rather than full sized, the spacing between the backrest and the seat pan should be adjustable. The range of adjustability should be between 100 and 200 mm.

b. References: Requirements

1. Ayoub and Halcomb (1976): The space between the backrest and the seat pan should accommodate the operator's sacrum, permitting the backrest to support the lumbar spine. The opening should be adjustable so that the backrest can be raised higher than the largest anticipated L-5 vertebral sitting height.

2. Cakir et al. (1980): Both the spacing and angle of the backrest should be adjustable.

3. MIL-HDBK-759A (1981): Adjustable seatback spacing is preferred. The range of adjustability should be between 100 and 200 mm. If fixed spacing must be used, it should be 150 mm.

6.4.4 Backrest Angle

a. IOS Design Recommendation

The angle between the seat pan and the backrest should be between 100° and 115°, preferably 105°.

b. References: Requirements

1. Ayoub and Halcomb (1976): The backrest should swivel ±15° vertically about a horizontal axis, but it should not swivel so easily that it is wobbly.

2. Cakir et al. (1980): The angle of the backrest should be adjustable.

3. MIL-STD-1472C (1981): A backrest should be provided and should recline between 100° and 115°.

4. Woodson (1981): The angle between the seat pan and backrest should be approximately 105°.

6.4.5 Backrest Shape

a. IOS Design Recommendation

Full-sized seatbacks should not be contoured. Small-sized backrests with adjustable spacing should be curved slightly outward to support the outward curve of the spine in the thorax region and the inward curve of the spine in the lumbar region. Nonadjustable backrests should be flat, but cushioning should be used that can be compressed to provide a contour that supports the lumbar region of the spine.

b. References: Requirements

1. Ayoub and Halcomb (1976): The backrest should provide support to the lumbar area of the spine. It should be slightly concave horizontally and slightly convex vertically.

2. Cakir et al. (1980): The backrest should provide pelvic and lumbar support. The surface of the backrest should curve smoothly outward and cause no pressure points on the operator's body surface.

3. IBM Corporation (1979): The backrest helps support the inward curve of the lower spine and may also relieve pressure on the spine.

4. MIL-HDBK-759A (1981): Seat cushions should be shaped to follow the inward curve of the lower back in order to provide adequate support for it and relieve strain on the back muscles.

5. MIL-STD-1472C (1981): The backrest should support the lumbar and thoracic areas of the back. It should be possible for the occupants to bring their eyes to the "eye line" with no more than 75 mm of forward body movement.

6. Woodson (1981): The use of backrest contouring should be avoided.

6.5 Armrests

Armrests should be provided where mobility of the trunk, shoulders, and arms is not frequently required. When continuous activity is necessary, armrests should probably not be used because they can interfere with task performance.

6.5.1 Armrest Length

a. IOS Design Recommendation

Armrests that are integral with the chair should be between 200 and 255 mm in length.

b. References: Requirements

1. Ayoub and Halcomb (1976): Armrests can relieve pressure on the spinal column and aid in changing positions and getting into and out of the chair. They can hinder the performance of tasks when mobility of the trunk, shoulders, and arms is necessary. Armrests should not be so long that they prevent the user from sitting close to the table in the prescribed position.

2. MIL-HDBK-759A (1981): An armrest length of 255 mm is recommended.

3. MIL-STD-1472C (1981): Armrests that are integral with the chair should be 200 mm in length.

6.5.2 Armrest Width

a. IOS Design Recommendation

Armrests that are integral with the chair should be 50 mm wide.

b. References: Requirements

1. MIL-HDBK-759A (1981): The recommended width of the armrests is 50 mm.

2. MIL-STD-1472C (1981): Armrests that are integral with the chair should be at least 50 mm wide.

6.5.3 Armrest Height

a. IOS Design Recommendation

When possible, the height of the armrest should be adjustable, with an adjustment range from 190 mm to 280 mm. For fixed-position armrests, the height should be approximately 215 mm.

b. References: Requirements

1. Ayoub and Halcomb (1976): Armrests should be positioned 1 or 2 in. above the mean anthropometric measurement for most users. Operators can adjust to the fixed armrest height by either positioning the upper arm fore/aft or elevating the shoulders.

2. MIL-HDBK-759A (1981): The recommended height from the seat surface to the top surface of the armrests is 215 mm.

3. MIL-STD-1472C (1981): Armrests should be adjustable from 190 to 280 mm above the compressed sitting surface.

6.5.4 Armrest Separation

a. IOS Design Recommendation

The armrests should be far enough apart to allow the operator to get in and out of the chair easily, but not so far apart that the operator has to stretch the elbows excessively to reach them. A separation of 460 mm is recommended.

b. Reference

The recommended separation of 460 mm is contained in MIL-HDBK-759A (1981).

6.6 Footrests

6.6.1 Applications

a. IOS Design Recommendation

A footrest should be used to enable a proper sitting posture and a proper relationship with the work surface. The correct posture is when the thighs are horizontal and the feet are resting on the footrest, with a 90° or slightly larger angle at the knees.

b. References: Requirements

1. Ayoub and Halcomb (1976): A footrest is advantageous when the seat pan is too high for the operator.

2. Cakir et al. (1980): When the height of the work surface is fixed and the seat height is adjustable, the correct leg posture for a small-sized operator is possible only with the aid of a footrest. The correct posture is when the thighs are horizontal and the feet are resting on the footrest, with a 90° or slightly larger angle at the knees.

3. IBM Corporation (1979): A footrest may be required to enable the proper sitting posture and a proper relationship with the work surface. If a footrest is used, it should be large enough to permit repositioning of the feet from time to time.

4. MIL-HDBK-759A (1981): Whenever operators are required to work for extended periods in seats higher than 460 mm or with work surfaces higher than 760 mm, a footrest should be provided.

6.6.2 Footrest Size

a. IOS Design Recommendation

The footrest should be large enough to permit leg and posture changes. Horizontal rods or foot rings attached to the table or seat should be avoided.

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b. References: Requirements

1. Ayoub and Halcomb (1976): Leg and posture changes are hindered by the use of very small footrests, and horizontal rods or foot rings should not be attached to the table or seat.

2. Cakir et al. (1980): Footrests should be large enough to accommodate the entire foot.

3. IBM Corporation (1979): The footrest should be large enough to permit operators to reposition their feet from time to time.

4. MIL-HDBK-759A (1981): A footrest length of 255 mm and width of 150 mm are recommended.

6.6.3 Footrest Height and Inclination

a. IOS Design Recommendation

When possible, both the height and inclination of the footrest should be adjustable. The range of adjustment should be from 0 to 50 mm for height and from 10° to 30° for inclination. A heel stop should be provided if the footrest is inclined more than 15° from the horizontal.

b. References: Requirements

1. Ayoub and Halcomb (1976): The inclination of the footrest may be up to 30°, but a heel stop should be provided if the footrest is inclined more than 15° from the horizontal. The angle from the base of the foot to the lower leg should be about 90° to 100°. Also, the footrest surface should be concave to facilitate normal movements.

2. Cakir et al. (1980): Footrests should be adjustable both in height and inclination, with the range of adjustability from 0 to 50 mm for height and 10 to 15° for inclination. To prevent the footrest from sliding, it should be secured to the floor, but movable footrests are better than none at all.

7. ANTHROPOMETRIC DATA

7.1 Introduction

Anthropometric data should be routinely used in workstation design activities to ensure that all workstation dimensions are compatible with the body sizes and reach distances of the anticipated users. The proper application of the data will minimize the movements required to view the displays and reach the controls, as well as maximize operator comfort for relatively long periods of operation. In this section, the anthropometric data for 20 common body measurements are provided; and the reach distances of both males and females are presented.

7.2 General Requirements

Even though a proposed IOS design is based on the available anthropometric data, a static mockup (cardboard or foam-core paneling will suffice) should be constructed and evaluated to ensure that the design will accommodate the range of anticipated users. A sample of subjects representing the low end (5th percentile) and high end (95th percentile) of the scale on each important body dimension should be used in the evaluation. Also, because the physical characteristics of the user population may change over time, it is advisable to provide adjustable or movable workstation components whenever possible.

7.3 Body Size Data

7.3.1 Data Source

The body size data presented herein were extracted from DoD-HDBK-743 [Metric] (1980). Of the 192 static body measurements therein, 20 are used here. These measurements were selected on the basis of their applicability to workstation design for seated operations. The measures are for men and women in the military services; civilian data are not included. The body measurements were taken on men wearing only undershorts and women wearing only bra and panties. Thus, sufficient allowances for clothing should be added to the measurements. Additionally, the anthropometric measures were taken with subjects sitting erect. Because this is not a typical posture, the measurements should be corrected for slumped posture. Eye height is about 4.5 cm lower in a slumped state than when sitting erect.

7.3.2 Data Application

The steps to be employed in the application of the anthropometric data are as follows:

a. Determine the relevant physical dimensions for the specific workstation design problem.
b. Define the user population.
c. Select the range of users to be accommodated (e.g., 5th percentile female to 95th percentile male).
d. Extract the percentile data from the data tables corresponding to the selected body dimensions.
e. Add the appropriate data correction factors for clothing and posture.

7.3.3 Body Dimensions

The various body dimensions are illustrated in Figures 7-1 through 7-20. The definition of each dimension and the corresponding tables of statistical and percentile values are included along with the figures. Both the graphics and the definitions in these figures are from Webb Associates (1978).

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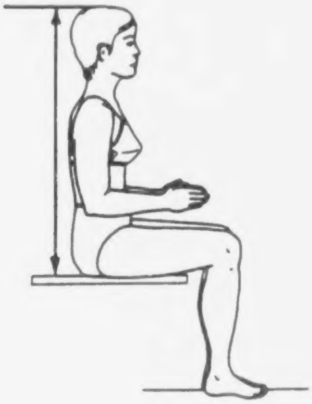
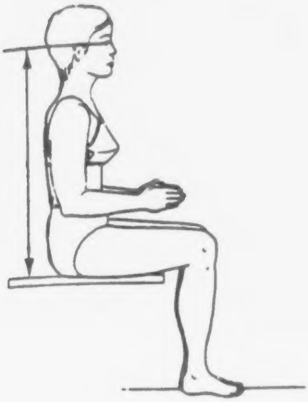


Definition: The vertical distance from the sitting surface to the top of the head, measured with the subject sitting erect and looking straight ahead.

Statistical Values: Table 7-1a.

Percentile Values: Table 7-1b.

Figure 7-1. Sitting Height.

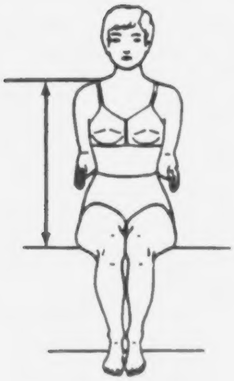


Definition: The vertical distance from the sitting surface to the outer corner of the eye, measured with the subject sitting erect and looking straight ahead.

Statistical Values: Table 7-2a.

Percentile Values: Table 7-2b.

Figure 7-2. Eye Height, Sitting.

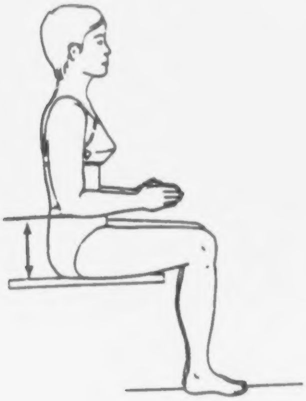


Definition: The vertical distance from the sitting surface to the surface of the shoulder halfway between the neck and the point of the shoulder. The subject sits erect with the upper arms relaxed and the forearms and hands extended forward horizontally.

Statistical Values: Table 7-3a.

Percentile Values: Table 7-3b.

Figure 7-3. Midshoulder Height, Sitting.



Definition: The vertical distance from the sitting surface to the bottom tip of the elbow. The subject sits erect with the upper arms relaxed and the forearms and hands extended forward horizontally.

Statistical Values: Table 7-4a.

Percentile Values: Table 7-4b.

Figure 7-4. Elbow Rest Height.

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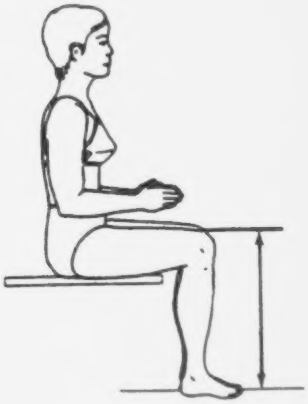
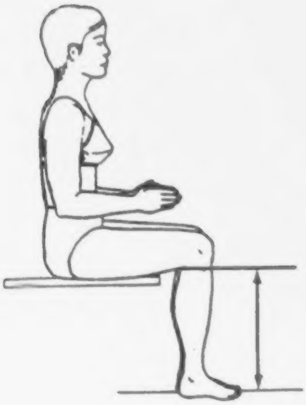


Definition: The vertical distance from the footrest surface to the top of the knee, measured with the subject sitting erect and with the knees and ankles at right angles.

Statistical Values: Table 7-5a.

Percentile Values: Table 7-5b.

Figure 7-5. Knee Height, Sitting.

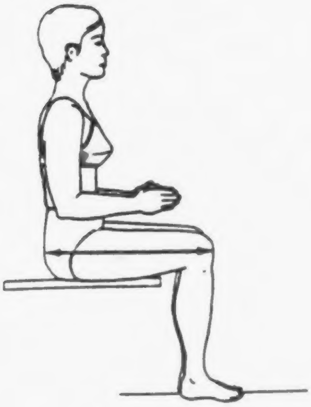


Definition: The vertical distance from the footrest surface to the underside of the thigh immediately behind the knee. The subject sits erect with the knees and ankles at right angles.

Statistical Values: Table 7-6a.

Percentile Values: Table 7-6b.

Figure 7-6. Popliteal Height.

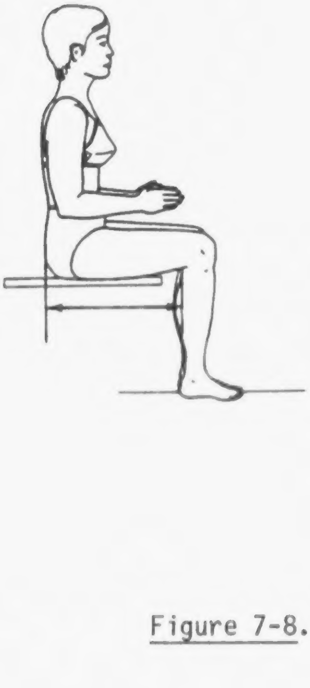


Definition: The horizontal distance from the back of the buttock to the front of the knee, measured with the subject sitting erect and with the knees and ankles at right angles.

Statistical Values: Table 7-7a.

Percentile Values: Table 7-7b.

Figure 7-7. Buttock-Knee Length.

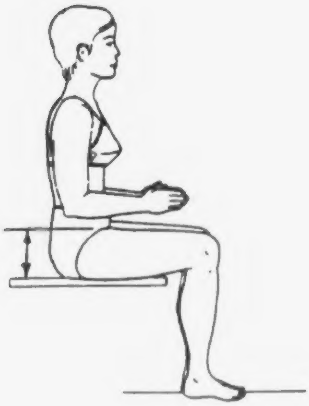


Definition: The horizontal distance from the back of the buttock to the back of the lower leg just below the knee. The subject sits erect with the knees and ankles at right angles.

Statistical Values: Table 7-8a.

Percentile Values: Table 7-8b.

Figure 7-8. Buttock-Popliteal Length.

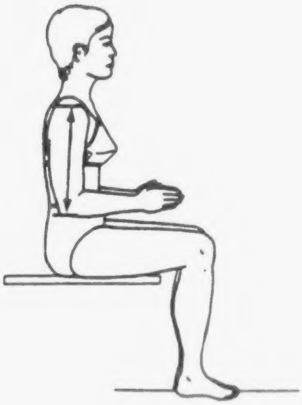


Definition: The vertical distance from the sitting surface to the highest point of the thigh. The subject sits erect with the knees and ankles at right angles.

Statistical Values: Table 7-9a.

Percentile Values: Table 7-9b.

Figure 7-9. Thigh Clearance.

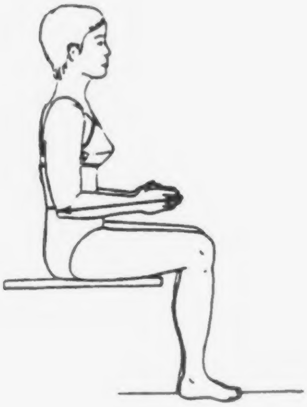


Definition: The vertical length of the upper arm from the point of the shoulder to the bottom of the elbow. The subject sits erect with the upper arms vertical and the forearms and hands extended forward horizontally.

Statistical Values: Table 7-10a.

Percentile Values: Table 7-10b.

Figure 7-10. Shoulder-Elbow Length.

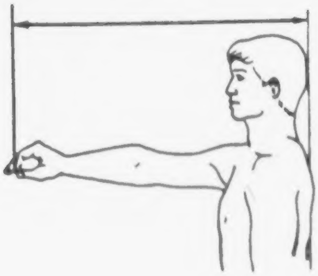


Definition: The horizontal distance from the back of the elbow to the tip of the middle finger. The subject sits erect with the upper arms vertical and the forearms and hands extended forward horizontally.

Statistical Values: Table 7-11a.

Percentile Values: Table 7-11b.

Figure 7-11. Elbow-Fingertip Length.

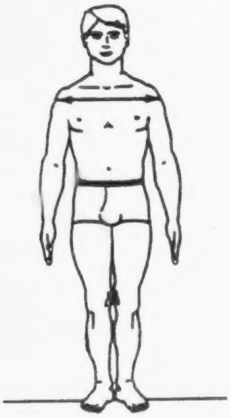


Definition: The horizontal distance from the wall to the tip of the thumb. The subject's back is against the wall, with the arm extended forward and the index finger touching the tip of the thumb.

Statistical Values: Table 7-12a.

Percentile Values: Table 7-12b.

Figure 7-12. Functional (Thumb-Tip) Reach.

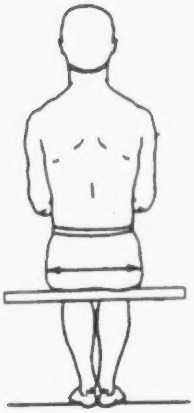


Definition: The horizontal distance across the upper arms between the maximum bulges of the deltoid muscles. The subject stands erect with the arms hanging naturally.

Statistical Values: Table 7-13a.

Percentile Values: Table 7-13b.

Figure 7-13. Shoulder (Bideltoid) Breadth.

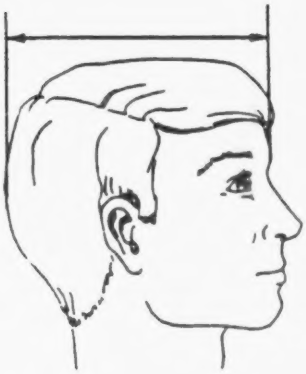


Definition: The maximum horizontal distance across the widest part of the hips. The subject sits erect, with upper arms relaxed, forearms and hands extended forward horizontally, the thighs completely supported by the sitting surface, and the long axis of the thighs parallel.

Statistical Values: Table 7-14a.

Percentile Values: Table 7-14b.

Figure 7-14. Hip Breadth, Sitting.

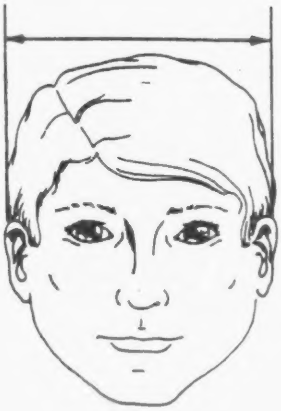


Definition: The maximum length of the head, measured from the most anterior point of the forehead between the brow ridges to the back of the head.

Statistical Values: Table 7-15a.

Percentile Values: Table 7-15b.

Figure 7-15. Head Length.



Definition: The maximum horizontal breadth of the head, measured behind the ears.

Statistical Values: Table 7-16a.

Percentile Values: Table 7-16b.

Figure 7-16. Head Breadth.

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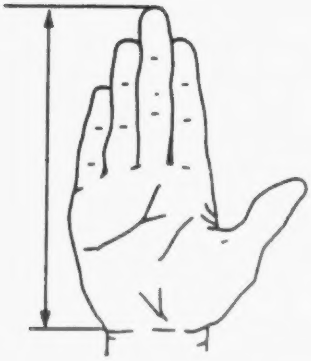
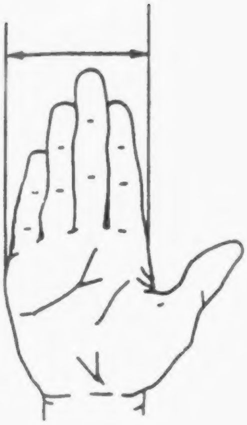


Definition: The distance from the base of the hand at the wrist crease to the tip of the middle finger, measured with the hand flat on a table, palm up, and the fingers together and straight.

Statistical Values: Table 7-17a.

Percentile Values: Table 7-17b.

Figure 7-17. Hand Length.

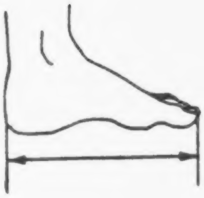


Definition: The breadth of the hand between the ends of the metacarpal bones, measured with the hand flat on a table, palm down, and with the fingers together and straight.

Statistical Values: Table 7-18a.

Percentile Values: Table 7-18b.

Figure 7-18. Hand Breadth.

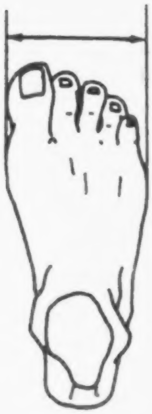


Definition: The length of the foot from the back of the heel to the tip of the longest toe. The subject stands with weight equally distributed on both feet.

Statistical Values: Table 7-19a.

Percentile Values: Table 7-19b.

Figure 7-19. Foot Length.



Definition: The maximum horizontal distance across the foot, measured at right angles to the long axis. The subject stands with weight equally distributed on both feet.

Statistical Values: Table 7-20a.

Percentile Values: Table 7-20b.

Figure 7-20. Foot Breadth.

7.3.4 Statistical Data

Both statistical values and percentile values for each of the 20 body dimensions are presented in the statistical tables in Section 7.3.4.3. These tables delineate the range of variation in body size of various groups for use in ascertaining the minimum and maximum design requirements to accommodate the anticipated user personnel.

7.3.4.1 Statistical Values

The statistical values for the 20 body dimensions are presented in the "a" tables in Section 7.3.4.3. The values for each group of subjects measured are provided, and the dates that the measures were obtained are also indicated. The various statistical measures contained in the tables are defined below:

a. N: The number of subjects measured in each group.

b. Mean: The arithmetic average for a body dimension.

c. SE(M): The standard error of the mean, which is an estimate of the magnitude of the sampling error. It is computed by dividing the standard deviation by the square root of the sample size.

d. S.D.: The standard deviation.

e. SE(S.D.): The standard error of the standard deviation, which is an estimate of the magnitude of the sampling error. It is computed by dividing the standard deviation by the square root of twice the sample size.

f. V(%): The coefficient of variation, which is the standard deviation expressed as a percentage of the mean.

g. Range: The range of values, consisting of the smallest measurement (Min), the largest measurement (Max), and the total range as computed by subtracting the minimum value from the maximum value.

h. Stature Ratio: The stature ratio represents the body dimension in relation to stature. It is obtained by dividing the mean value for the dimension by the mean value of stature for that group. The stature ratio is an indication of body proportion.

7.3.4.2 Percentile Values

The most commonly used percentile values are presented for each of the 20 body dimensions in the "b" tables in Section 7.3.4.3. The percentiles are shown for each of the groups of subjects measured, along with the date the measures were obtained. The 50th percentile is equivalent to the median. The range is the 1st percentile value subtracted from the 99th percentile value. The 1st percentile value indicates that 1 percent of the subjects in the sample are smaller than the value, whereas the 99th percentile value indicates that 1 percent are larger than the value for that body dimension. Percentile values cannot be combined to describe a composite "small," "medium," or "large" body size because an individual on one given percentile body dimension will not necessarily be at the same percentile for other dimensions.

7.3.4.3 Statistical Tables

The statistical values are provided in Tables 7-1a through 7-20a, and the percentile values are shown in Tables 7-1b through 7-20b. To facilitate locating the statistical data, the "a" and "b" tables corresponding to each body dimension are produced on consecutive, facing pages.

Table 7-1a. Statistical Values for Sitting Height
(From DoD-HDBK-743 [Metric], 1980.)

								Range			Stature
No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Min.	Max.	Total	ratio
1	USAF Flying Pers. (1967)	2420	93.18	0.06	3.18	0.05	3.41	80.9	104.8	23.9	.525
2	US Navy Aviators (1964)	1549	92.14	0.08	3.16	0.06	3.43	81.8	105.6	23.8	.519
3	US Navy Recruits (1966)	4095	91.60	0.05	3.43	0.04	3.74	79.7	104.5	24.8	.522
4	USAF Flying Pers. (1950)	4000	91.30	0.05	3.23	0.04	3.54	76.7	102.3	25.6	.520
5	USA Basic Trainees (1966)	2639	91.22	0.07	3.44	0.05	3.77	79.2	103.2	24.0	.522
6	USAF Basic Trainees (1965)	2527	91.12	0.07	3.48	0.05	3.82	78.8	102.7	23.9	.520
7	US Marine Corps (1966)	2008	90.99	0.08	3.53	0.06	3.88	80.4	100.9	20.5	.521
8	US Army Aviators (1970)	1482	90.92	0.08	3.23	0.06	3.56	78.9	101.6	22.7	.521
9	US Army Men (1946)	24,352	90.88	0.02	3.41	0.01	3.75	77.0	105.0	28.0	.523
10	US Army Men (1966)	6682	90.69	0.04	3.66	0.03	4.04	77.5	102.9	25.4	.520
11	USAF Women (1968)	1905	85.60	0.07	3.17	0.05	3.70	75.4	96.4	21.0	.528
12	US Army Women (1977)	1331	85.08	0.10	3.59	0.07	4.22	73.1	96.2	23.1	.522
13	US Army Women (1946)	8119	83.66	0.04	3.19	0.03	3.83	71.0	97.0	26.0	.516

Note. Values in centimeters.

Table 7-1b. Percentile Values for Sitting Height
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	86.2	87.0	88.1	89.2	91.0	93.1	95.3	97.4	98.6	99.8	100.6	14.4
2	US Navy Aviators (1964)	85.0	85.8	87.0	88.1	90.0	92.1	94.2	96.2	97.4	98.9	100.0	15.0
3	US Navy Recruits (1966)	83.6	84.6	86.0	87.2	89.2	91.5	93.9	96.1	97.4	98.8	99.7	16.1
4	USAF Flying Pers. (1950)	83.8	84.6	86.0	87.1	89.1	91.3	93.5	95.4	96.6	97.9	98.8	15.0
5	USA Basic Trainees (1966)	82.8	83.9	85.5	86.8	88.9	91.2	93.5	95.6	96.9	98.4	99.4	16.6
6	USAF Basic Trainees (1965)	82.8	83.8	85.3	86.6	88.8	91.1	93.5	95.5	96.8	98.3	99.3	16.5
7	US Marine Corps (1966)	83.1	83.9	85.2	86.4	88.6	91.0	93.4	95.6	96.9	98.4	99.4	16.3
8	US Army Men (1946)	82.6	83.6	85.1	86.4	88.4	90.9	93.2	95.2	96.5	98.0	99.1	16.5
9	US Army Aviators (1970)	83.3	84.3	85.7	86.8	88.8	90.9	93.1	95.1	96.3	97.7	98.6	15.3
10	US Army Men (1966)	82.0	83.0	84.5	85.9	88.2	90.8	93.2	95.4	96.7	98.2	99.2	17.2
11	USAF Women (1968)	78.7	79.3	80.4	81.5	83.4	85.6	87.8	89.7	90.9	92.2	93.0	14.3
12	US Army Women (1977)	76.3	77.4	79.0	80.4	82.7	85.2	87.6	89.7	90.8	92.0	92.7	16.4
13	US Army Women (1946)	76.2	77.1	78.4	79.6	81.5	83.7	85.8	87.8	88.9	90.2	91.1	14.9

Note. Percentiles in centimeters.

Table 7-2a. Statistical Values for Eye Height, Sitting
(From DoD-HDBK-743 [Metric], 1980.)

								Range			Stature
No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Min.	Max.	Total	ratio
1	USAF Flying Pers. (1967)	2420	80.95	0.06	3.02	0.04	3.73	68.5	91.0	22.5	.456
2	US Navy Aviators (1964)	1549	80.18	0.08	3.01	0.05	3.75	71.2	90.6	19.4	.451
3	USAF Flying Pers. (1950)	4000	79.96	0.05	3.19	0.04	3.99	67.0	93.7	26.7	.455
4	US Navy Recruits (1966)	4095	79.88	0.05	3.17	0.03	3.96	67.5	90.8	23.2	.456
5	USAF Basic Trainees (1965)	2527	79.77	0.07	3.30	0.05	4.14	66.8	90.7	23.9	.456
6	USA Basic Trainees (1966)	2639	79.12	0.07	3.39	0.05	4.29	66.8	90.7	23.9	.453
7	US Army Aviators (1970)	1482	78.80	0.08	3.16	0.06	4.02	67.6	88.8	21.2	.451
8	US Army Men (1966)	6682	78.72	0.04	3.57	0.03	4.53	65.9	92.1	26.2	.451
9	US Marine Corps (1966)	2008	78.64	0.07	3.34	0.05	4.25	68.2	88.5	20.3	.450
10	USAF Women (1968)	1905	73.70	0.07	3.06	0.05	4.15	64.0	83.1	19.1	.455
11	US Army Women (1977)	1331	73.64	0.09	3.46	0.07	4.71	62.5	84.1	21.6	.452

Note. Values in centimeters.

Table 7-2b. Percentile Values for Eye Height, Sitting
(From DoD-HDBK-743 [Metric], 1980.)

							Median						Range
No.	Group (Year)	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	(1st-99th)
1	USAF Flying Pers. (1967)	74.1	74.9	76.2	77.2	78.9	80.9	82.9	84.9	86.1	87.5	88.3	14.2
2	US Navy Aviators (1964)	73.2	74.1	75.4	76.5	78.2	80.1	82.1	84.1	85.4	86.8	87.7	14.5
3	USAF Flying Pers. (1950)	72.4	73.3	74.7	75.9	77.8	80.0	82.1	84.0	85.2	86.5	87.4	15.0
4	USAF Basic Trainees (1965)	71.9	72.8	74.2	75.4	77.6	79.9	82.1	84.0	85.1	86.5	87.4	15.5
5	US Navy Recruits (1966)	72.6	73.5	74.8	75.9	77.7	79.8	82.0	84.1	85.3	86.6	87.4	14.8
6	USA Basic Trainees (1966)	71.2	72.1	73.4	74.7	76.8	79.2	81.4	83.5	84.7	86.2	87.2	16.0
7	US Army Men (1966)	70.1	71.2	72.8	74.1	76.4	78.8	81.2	83.3	84.6	86.1	87.0	16.9
8	US Army Aviators (1970)	71.3	72.2	73.6	74.8	76.7	78.8	80.9	82.8	84.0	85.5	86.5	15.2
9	US Marine Corps (1966)	70.7	71.6	72.9	74.2	76.4	78.8	81.0	82.0	84.0	85.2	86.1	15.4
10	US Army Women (1977)	65.3	66.2	67.7	69.1	71.4	73.8	76.0	77.9	79.1	80.6	81.6	16.3
11	USAF Women (1968)	66.9	67.6	68.7	69.8	71.6	73.7	75.7	77.7	78.8	80.2	81.1	14.2

Note. Percentiles in centimeters.

Table 7-3a. Statistical Values for Midshoulder Height, Sitting (From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	64.59	0.06	2.74	0.04	4.24	54.0	74.6	20.6	.364
2	USAF Basic Trainees (1965)	2527	63.00	0.06	2.94	0.04	4.67	53.8	71.7	17.9	.360
3	US Army Aviators (1970)	1482	62.90	0.07	2.77	0.05	4.41	50.9	71.1	20.2	.360
4	US Navy Recruits (1966)	4095	62.71	0.05	3.01	0.03	4.79	50.9	73.1	22.2	.358
5	USA Basic Trainees (1966)	2639	62.70	0.06	2.93	0.04	4.68	52.2	73.2	21.0	.359
6	US Army Men (1966)	6682	62.38	0.04	3.18	0.03	5.09	50.8	73.1	22.3	.357
7	US Marine Corps (1966)	2008	62.38	0.07	3.19	0.05	5.11	51.7	71.3	19.6	.357
8	USAF Women (1968)	1905	58.00	0.06	2.66	0.04	4.59	51.0	67.2	16.2	.358

Note. Values in centimeters.

Table 7-3b. Percentile Values for Midshoulder Height, Sitting
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	Median 25th	50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	58.3	59.1	60.2	61.2	62.7	64.5	66.4	68.2	69.2	70.4	71.1	12.8
2	USAF Basic Trainees (1965)	56.1	56.9	58.1	59.2	61.0	63.0	65.0	66.8	67.8	69.1	70.0	13.9
3	US Army Aviators (1970)	56.3	57.2	58.3	59.4	61.0	62.9	64.8	66.5	67.5	68.6	69.3	13.0
4	US Navy Recruits (1966)	55.6	56.5	57.8	58.9	60.7	62.7	64.7	66.6	67.8	69.0	69.8	14.2
5	USA Basic Trainees (1966)	55.8	56.7	58.0	59.0	60.7	62.7	64.6	66.5	67.6	68.9	69.7	13.9
6	US Army Men (1966)	54.5	55.6	57.1	58.4	60.3	62.4	64.5	66.5	67.6	68.9	69.7	15.2
7	US Marine Corps (1966)	54.9	55.8	57.2	58.3	60.2	62.4	64.6	66.6	67.7	68.8	69.5	14.6
8	USAF Women (1968)	52.3	52.8	53.7	54.6	56.1	57.9	59.8	61.5	62.5	63.6	64.4	12.1

Note. Percentiles in centimeters.

Table 7-4a. Statistical Values for Elbow Rest Height
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Max.	Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	25.16	0.05	2.61	0.04	10.36	15.7	35.1	19.4	.142
2	USAF Basic Trainees (1965)	2527	23.55	0.06	2.78	0.04	11.80	14.2	33.8	19.6	.135
3	US Navy Aviators (1964)	1549	23.50	0.06	2.52	0.05	10.71	15.2	33.0	17.8	.132
4	USAF Flying Pers. (1950)	4000	23.17	0.04	2.59	0.03	11.18	13.4	33.0	19.6	.132
5	US Army Aviators (1970)	1482	23.10	0.07	2.65	0.05	11.45	14.8	31.9	17.1	.132
6	USAF Women (1968)	1905	22.71	0.06	2.46	0.04	10.83	15.1	29.5	14.4	.140
7	US Army Women (1977)	255	20.73	0.17	2.74	0.12	13.20	11.1	28.0	16.9	.127

Note. Values in centimeters.

Table 7-4b. Percentile Values for Elbow Rest Height
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	19.1	19.9	20.9	21.9	23.4	25.1	26.9	28.5	29.5	30.7	31.5	12.4
2	USAF Basic Trainees (1965)	16.8	17.6	18.8	19.9	21.7	23.7	25.4	27.0	28.0	29.1	30.0	13.2
3	US Navy Aviators (1964)	17.8	18.4	19.4	20.3	21.8	23.5	25.2	26.7	27.7	28.9	29.8	12.0
4	USAF Flying Pers. (1950)	17.0	17.8	18.9	19.9	21.5	23.2	24.9	26.5	27.4	28.4	29.0	12.0
5	US Army Aviators (1970)	16.5	17.4	18.7	19.8	21.4	23.1	24.8	26.4	27.4	28.6	29.4	12.9
6	USAF Women (1968)	17.3	17.9	18.7	19.5	21.0	22.7	24.4	25.9	26.9	28.0	28.8	11.5
7	US Army Women (1977)	14.7	15.2	16.1	17.1	18.9	20.8	22.6	24.1	25.0	26.2	27.0	12.3

Note. Percentiles in centimeters.

Table 7-5a. Statistical Values for Knee Height, Sitting
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	55.76	0.05	2.49	0.04	4.47	47.7	64.2	16.5	.314
2	US Navy Aviators (1964)	1549	55.48	0.06	2.48	0.04	4.47	48.2	63.8	15.6	.312
3	USAF Basic Trainees (1965)	2527	55.36	0.05	2.63	0.04	4.75	46.0	64.7	18.7	.316
4	USAF Flying Pers. (1950)	4000	55.04	0.04	2.48	0.03	4.51	45.7	63.7	18.0	.314
5	US Army Men (1946)	24,419	54.91	0.02	2.76	0.01	5.03	39.0	69.0	30.0	.316
6	US Marine Corps (1966)	2008	54.23	0.06	2.63	0.04	4.84	45.8	63.7	17.9	.311
7	US Army Men (1966)	6682	54.06	0.03	2.73	0.02	5.05	44.3	64.5	20.2	.310
8	USA Basic Trainees (1966)	2639	54.02	0.05	2.63	0.04	4.87	46.2	64.2	18.0	.309
9	US Navy Recruits (1966)	4095	53.68	0.04	2.64	0.03	4.92	44.4	63.5	19.1	.306
10	US Army Aviators (1970)	1482	53.01	0.07	2.57	0.05	4.84	45.6	62.5	16.9	.304
11	US Army Women (1977)	1331	50.99	0.07	2.60	0.05	5.11	43.4	60.7	17.3	.313
12	US Army Women (1946)	8117	47.67	0.03	2.39	0.02	5.07	38.0	57.0	19.0	.294

Note. Values in centimeters.

Table 7-5b. Percentile Values for Knee Height, Sitting
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	50.1	50.8	51.7	52.6	54.1	55.7	57.4	59.0	59.9	61.1	61.9	11.8
2	US Navy Aviators (1964)	50.1	50.6	51.5	52.3	53.7	55.4	57.2	58.8	59.7	60.7	61.4	11.3
3	USAF Basic Trainees (1965)	49.4	50.1	51.2	52.1	53.6	55.3	57.1	58.7	59.8	61.1	62.0	12.6
4	USAF Flying Pers. (1950)	49.5	50.1	51.0	51.9	53.4	55.0	56.7	58.2	59.1	60.2	60.9	11.4
5	US Army Men (1946)	48.3	49.0	50.3	51.3	53.1	54.9	56.9	58.7	59.7	61.0	61.7	13.4
6	US Marine Corps (1966)	48.4	49.0	50.0	50.8	52.4	54.2	56.0	57.7	58.6	59.6	60.3	11.8
7	US Army Men (1966)	47.7	48.5	49.7	50.7	52.2	54.0	55.9	57.6	58.7	59.9	60.6	12.9
8	USA Basic Trainees (1966)	48.0	48.8	49.8	50.8	52.2	53.9	55.8	57.5	58.6	59.7	60.4	12.4
9	US Navy Recruits (1966)	47.8	48.5	49.5	50.4	51.9	53.6	55.4	57.1	58.2	59.4	60.2	12.4
10	US Army Aviators (1970)	47.2	47.9	48.9	49.8	51.3	52.9	54.6	56.3	57.4	58.7	59.7	12.5
11	US Army Women (1977)	45.5	46.0	46.9	47.7	49.2	50.9	52.7	54.4	55.5	56.6	57.3	11.8
12	US Army Women (1946)	42.2	42.7	43.7	44.6	46.1	47.7	49.2	50.7	51.6	52.8	53.6	11.4

Note. Percentiles in centimeters.

Table 7-6a. Statistical Values for Popliteal Height

(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	US Marine Corps (1966)	2008	45.74	0.05	2.40	0.04	5.25	37.3	52.9	15.6	.287
2	USAF Basic Trainees (1965)	2527	44.84	0.05	2.37	0.03	5.29	36.6	54.2	17.6	.256
3	USA Basic Trainees (1966)	2639	44.78	0.05	2.49	0.03	5.56	36.6	53.3	16.7	.256
4	US Army Men (1966)	6682	44.61	0.03	2.50	0.02	5.60	35.8	54.2	18.4	.256
5	US Navy Aviators (1964)	1549	43.98	0.06	2.18	0.04	4.96	37.0	51.0	14.0	.248
6	US Navy Recruits (1966)	4095	43.75	0.04	2.52	0.03	5.76	36.3	53.1	16.8	.250
7	USAF Flying Pers. (1967)	2420	43.70	0.05	2.25	0.03	5.14	36.5	51.2	14.7	.246
8	USAF Flying Pers. (1950)	4000	43.09	0.03	1.93	0.02	4.48	36.0	49.7	13.7	.245
9	US Army Aviators (1970)	1482	42.34	0.06	2.47	0.05	5.83	35.5	53.4	17.9	.243
10	US Army Women (1977)	1331	41.68	0.06	2.35	0.05	5.64	34.7	49.1	14.4	.256
11	USAF Women (1968)	1905	41.05	0.04	1.86	0.03	4.53	33.6	47.1	13.5	.253

Note. Values in centimeters.

Table 7-6b. Percentile Values for Popliteal Height
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	US Marine Corps (1966)	40.3	41.1	42.0	42.8	44.1	45.6	47.3	49.0	50.0	51.0	51.4	11.1
2	USAF Basic Trainees (1965)	39.6	40.2	41.1	41.9	43.2	44.8	46.3	47.9	48.9	50.1	51.0	11.4
3	USA Basic Trainees (1966)	39.1	39.8	40.7	41.6	43.0	44.7	46.5	48.0	49.0	50.0	50.6	11.5
4	US Army Men (1966)	38.8	39.6	40.6	41.5	42.9	44.5	46.3	47.9	48.8	49.8	50.4	11.6
5	US Navy Aviators (1964)	39.0	39.6	40.5	41.2	42.4	43.9	45.5	46.9	47.7	48.5	48.9	9.9
6	US Navy Recruits (1966)	38.3	38.7	39.5	40.4	42.0	43.8	45.5	47.0	47.8	48.9	49.7	11.4
7	USAF Flying Pers. (1967)	38.5	39.1	40.1	40.9	42.2	43.7	45.2	46.6	47.5	48.5	49.1	10.6
8	USAF Flying Pers. (1950)	38.8	39.2	40.0	40.6	41.8	43.1	44.4	45.6	46.3	47.2	47.7	8.9
9	US Army Aviators (1970)	36.8	37.4	38.4	39.2	40.6	42.3	44.0	45.6	46.6	47.8	48.6	11.8
10	US Army Women (1977)	36.4	37.0	38.0	38.8	40.1	41.6	43.2	44.8	45.7	46.7	47.3	10.9
11	USAF Women (1968)	36.2	36.9	38.0	38.8	39.9	41.0	42.2	43.3	44.1	45.1	45.9	9.7

Note. Percentiles in centimeters.

Table 7-7a. Statistical Values for Buttock-Knee Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range			Stature
								Min.	Max.	Total	ratio
1	US Navy Aviators (1964)	1549	61.20	0.06	2.54	0.05	4.15	52.6	70.6	18.0	.345
2	USAF Flying Pers. (1967)	2420	60.40	0.05	2.70	0.04	4.47	51.8	69.6	17.8	.341
3	USAF Basic Trainees (1965)	2527	60.28	0.06	2.92	0.04	4.84	48.8	71.2	22.4	.344
4	US Army Aviators (1970)	1482	60.19	0.07	2.63	0.05	4.37	52.9	69.4	16.5	.345
5	USAF Flying Pers. (1950)	4000	59.99	0.04	2.67	0.03	4.45	50.7	70.2	19.5	.342
6	US Marine Corps (1966)	2008	59.51	0.06	2.72	0.04	4.57	51.7	68.2	16.5	.341
7	US Army Men (1966)	6682	59.47	0.03	2.85	0.02	4.80	50.1	70.9	20.8	.341
8	US Army Men (1946)	24,244	59.43	0.02	2.85	0.01	4.80	49.0	71.0	22.0	.342
9	USA Basic Trainees (1966)	2639	59.24	0.05	2.77	0.04	4.68	50.2	70.2	20.0	.339
10	US Navy Recruits (1966)	4095	59.21	0.04	2.74	0.03	4.63	50.1	69.7	19.6	.338
11	US Army Women (1977)	1331	57.85	0.08	3.06	0.06	5.29	48.7	68.5	19.8	.355
12	USAF Women (1968)	1905	57.43	0.06	2.63	0.04	4.58	48.6	66.4	17.8	.354
13	US Army Women (1946)	8117	56.81	0.03	2.95	0.02	5.23	45.0	67.0	22.0	.350

Note. Values in centimeters.

Table 7-7b. Percentile Values for Buttock-Knee Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	US Navy Aviators (1964)	55.3	56.1	57.2	58.0	59.5	61.1	62.8	64.5	65.5	66.6	67.4	12.1
2	USAF Flying Pers. (1967)	54.3	55.0	56.1	57.0	58.6	60.3	62.1	63.9	65.0	66.3	67.3	13.0
3	USAF Basic Trainees (1965)	53.8	54.6	55.7	56.6	58.3	60.2	62.1	64.0	65.2	66.6	67.5	13.7
4	US Army Aviators (1970)	54.3	54.9	55.9	56.8	58.4	60.2	61.9	63.6	64.6	65.8	66.6	12.3
5	USAF Flying Pers. (1950)	53.9	54.6	55.6	56.6	58.2	60.0	61.8	63.4	64.4	65.7	66.5	12.6
6	US Army Men (1966)	52.9	53.7	54.9	55.9	57.5	59.4	61.3	63.2	64.3	65.6	66.5	13.6
7	US Marine Corps (1966)	53.5	54.2	55.2	56.1	57.6	59.4	61.3	63.2	64.2	65.3	66.0	12.5
8	US Army Men (1946)	52.6	53.3	54.6	55.6	57.4	59.4	61.5	63.0	64.0	65.3	66.0	13.4
9	USA Basic Trainees (1966)	53.2	53.8	54.8	55.7	57.3	59.2	61.1	62.8	63.9	65.3	66.2	13.0
10	US Navy Recruits (1966)	53.1	53.8	54.8	55.7	57.4	59.2	61.0	62.7	63.8	65.0	65.9	12.8
11	US Army Women (1977)	51.1	51.9	53.1	54.0	55.7	57.7	59.9	62.0	63.2	64.5	65.3	14.2
12	USAF Women (1968)	51.8	52.3	53.2	54.1	55.6	57.3	59.2	60.9	61.9	63.0	63.7	11.9
13	US Army Women (1946)	50.0	50.8	52.0	53.1	54.8	56.8	58.7	60.6	61.7	63.2	64.3	14.3

Note. Percentiles in centimeters.

Table 7-8a. Statistical Values for Buttock-Popliteal Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	50.37	0.05	2.58	0.04	5.12	42.5	59.8	17.3	.284
2	US Navy Aviators (1964)	1549	50.26	0.06	2.52	0.05	5.01	40.6	59.0	18.4	.283
3	US Marine Corps (1966)	2008	50.11	0.06	2.54	0.04	5.08	43.0	58.8	15.8	.287
4	US Army Men (1966)	6682	49.82	0.03	2.50	0.02	5.02	41.2	58.7	17.5	.285
5	USA Basic Trainees (1966)	2629	49.51	0.05	2.52	0.03	5.09	42.0	58.7	16.7	.283
6	USAF Basic Trainees (1965)	2525	49.36	0.05	2.65	0.04	5.37	37.2	59.2	22.0	.282
7	US Army Aviators (1970)	1482	49.09	0.07	2.59	0.05	5.28	42.7	58.9	16.2	.281
8	US Navy Recruits (1966)	4095	48.95	0.04	2.34	0.03	4.78	41.0	58.9	17.9	.279
9	USAF Women (1968)	1905	47.71	0.06	2.76	0.04	5.78	39.1	58.5	19.4	.294

Note. Values in centimeters.

Table 7-8b. Percentile Values for Buttock-Popliteal Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	44.6	45.2	46.1	47.0	48.6	50.4	52.1	53.6	54.6	55.8	56.6	12.0
2	US Navy Aviators (1964)	44.6	45.2	46.2	47.1	48.5	50.2	51.9	53.5	54.5	55.6	56.3	11.7
3	US Marine Corps (1966)	44.6	45.2	46.1	46.9	48.3	50.0	51.8	53.5	54.5	55.6	56.2	11.6
4	US Army Men (1966)	44.0	44.7	45.8	46.6	48.1	49.8	51.5	53.1	54.0	55.1	55.8	11.8
5	USA Basic Trainees (1966)	43.7	44.4	45.4	46.3	47.8	49.5	51.2	52.8	53.7	54.9	55.6	11.9
6	USAF Basic Trainees (1965)	43.6	44.2	45.2	46.1	47.5	49.3	51.1	52.8	53.9	55.2	56.2	12.6
7	US Army Aviators (1970)	43.7	44.1	44.9	45.7	47.2	49.1	50.9	52.5	53.4	54.4	55.0	11.3
8	US Navy Recruits (1966)	43.8	44.3	45.2	46.0	47.3	48.9	50.5	52.0	52.9	53.9	54.6	10.8
9	USAF Women (1968)	42.0	42.5	53.5	44.3	45.8	47.5	49.5	51.4	52.6	54.0	55.0	13.0

Note. Percentiles in centimeters.

Table 7-9a. Statistical Values for Thigh Clearance
(From DoD-HDBK-743 [Metric], 1980.)

								Range			Stature
No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Min.	Max.	Total	ratio
1	USAF Flying Pers. (1967)	2420	16.53	0.03	1.38	0.02	8.35	12.5	21.7	9.2	.093
2	USAF Basic Trainees (1965)	2527	15.03	0.03	1.36	0.02	9.05	11.4	20.3	8.9	.086
3	US Army Aviators (1970)	1482	14.71	0.04	1.41	0.03	9.65	10.5	19.8	9.3	.084
4	USAF Flying Pers. (1950)	4000	14.24	0.02	1.30	0.01	9.13	10.3	18.7	8.4	.081
5	US Army Women (1977)	255	15.41	0.08	1.31	0.06	8.50	12.2	19.9	7.7	.095
6	USAF Women (1968)	1905	12.44	0.03	1.25	0.02	10.05	9.0	16.9	7.9	.077

Note. Values in centimeters.

Table 7-9b. Percentile Values for Thigh Clearance
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	13.4	13.8	14.3	14.8	15.6	16.5	17.4	18.3	18.8	19.4	19.9	6.5
2	USAF Basic Trainees (1965)	12.2	12.6	13.0	13.4	14.1	14.9	15.9	16.9	17.5	18.2	18.6	6.4
3	US Army Aviators (1970)	11.6	11.9	12.4	12.9	13.8	14.7	15.6	16.5	17.0	17.7	18.2	6.6
4	USAF Flying Pers. (1950)	11.3	11.6	12.1	12.6	13.3	14.2	15.1	15.9	16.4	16.9	17.2	5.9
5	US Army Women (1977)	12.5	12.7	13.2	13.7	14.6	15.4	16.2	17.0	17.5	18.3	18.9	6.4
6	USAF Women (1968)	9.8	10.0	10.4	10.8	11.5	12.4	13.3	14.1	14.6	15.1	15.5	5.7

Note. Percentiles in centimeters.

Table 7-10a. Statistical Values for Shoulder-Elbow Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	US Marine Corps (1966)	2008	37.12	0.04	1.84	0.03	4.96	31.8	43.2	11.4	.213
2	US Navy Recruits (1966)	4095	36.87	0.03	1.83	0.02	4.97	30.5	43.4	12.9	.210
3	US Army Men (1966)	6682	36.87	0.02	1.86	0.02	5.05	29.7	43.6	13.9	.211
4	US Navy Aviators (1964)	1549	36.81	0.04	1.70	0.03	4.61	30.8	43.2	12.4	.207
5	USA Basic Trainees (1966)	2639	36.78	0.04	1.81	0.02	4.92	30.8	43.4	12.6	.211
6	US Army Aviators (1970)	1482	36.71	0.05	1.78	0.03	4.85	31.7	42.5	10.8	.210
7	USAF Basic Trainees (1965)	2527	36.46	0.04	1.81	0.03	4.96	30.8	42.4	11.6	.208
8	USAF Flying Pers. (1950)	4000	36.37	0.03	1.72	0.02	4.73	29.5	43.1	13.6	.207
9	US Army Men (1946)	24,556	36.28	0.01	2.06	0.00	5.68	25.0	49.0	24.0	.209
10	USAF Flying Pers.	2420	35.95	0.03	1.71	0.02	4.76	30.7	42.7	12.0	.203
11	US Army Women (1977)	1331	33.56	0.05	1.75	0.03	5.21	27.3	40.2	12.9	.206
12	US Army Women (1946)	8119	33.20	0.02	1.84	0.01	5.62	25.0	41.0	16.0	.205

Note. Values in centimeters.

Table 7-10b. Percentile Values for Shoulder-Elbow Length
(From DoD-HDBK-743 [Metric], 1980.)

						Median						Range
No.	Group (Year)	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	(1st-99th)
1	US Marine Corps (1966)	33.0	33.4	34.1	34.7	35.8	37.1	38.4	39.5	40.2	41.0	41.5	8.5
2	US Navy Recruits (1966)	32.7	33.2	33.9	34.5	35.6	36.9	38.1	39.2	39.9	40.7	41.3	8.6
3	US Army Men (1966)	32.6	33.1	33.8	34.5	35.6	36.8	38.1	39.3	40.0	40.8	41.3	8.7
4	USA Basic Trainees (1966)	32.7	33.1	33.8	34.4	35.6	36.8	38.0	39.1	39.8	40.6	41.2	8.5
5	US Navy Aviators (1964)	33.0	33.4	34.1	34.7	35.7	36.8	37.9	39.0	39.6	40.4	40.9	7.9
6	US Army Aviators (1970)	32.7	33.1	33.8	34.4	35.5	36.7	37.9	39.0	39.7	40.5	41.1	8.4
7	USAF Basic Trainees (1965)	32.4	32.8	33.5	34.1	35.2	36.5	37.7	38.8	39.4	40.2	40.8	8.4
8	USAF Flying Pers. (1950)	32.5	32.9	33.5	34.1	35.2	36.4	37.6	38.6	39.2	39.9	40.3	7.8
9	US Army Men (1946)	31.2	31.8	32.8	33.5	34.8	36.3	37.6	38.9	39.6	40.6	41.4	10.2
10	USAF Flying Pers. (1967)	32.1	32.5	33.2	33.8	34.8	35.9	37.1	38.2	38.8	39.5	40.0	7.9
11	US Army Women (1977)	29.8	30.2	30.8	31.4	32.3	33.5	34.7	35.9	36.6	37.2	37.6	7.8
12	US Army Women (1946)	28.8	29.3	30.2	30.9	32.0	33.2	34.4	35.5	36.2	37.1	37.6	8.8

Note. Percentiles in centimeters.

Table 7-11a. Statistical Values for Elbow-Fingertip Length (From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	US Navy Aviators (1964)	1549	48.46	0.05	1.90	0.03	3.92	42.0	55.8	13.8	.273
2	US Army Aviators (1970)	1482	48.14	0.05	2.10	0.04	4.37	42.1	56.5	14.4	.276
3	US Army Men (1966)	6682	47.96	0.03	2.31	0.02	4.81	39.3	57.4	18.1	.275
4	USA Basic Trainees (1966)	2639	47.94	0.04	2.19	0.03	4.57	40.4	56.4	16.0	.274
5	USAF Flying Pers. (1950)	4000	47.88	0.03	2.03	0.02	4.24	39.6	54.8	15.2	.273
6	US Marine Corps (1966)	2008	47.82	0.05	2.22	0.04	4.64	39.9	55.7	15.8	.274
7	US Navy Recruits (1966)	4095	47.66	0.03	2.14	0.02	4.48	40.6	55.1	14.5	.272
8	US Army Men (1946)	24,354	47.58	0.01	2.23	0.00	4.69	37.5	59.5	22.0	.274
9	US Army Women (1977)	1331	43.52	0.06	2.28	0.04	5.25	37.1	51.0	13.9	.267
10	US Army Women (1946)	8118	42.36	0.02	2.09	0.02	4.98	33.0	52.0	19.0	.261

Note. Values in centimeters.

Table 7-11b. Percentile Values for Elbow-Fingertip Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	US Navy Aviators (1964)	44.4	44.8	45.4	46.0	47.1	48.4	49.8	51.0	51.7	52.4	52.9	8.5
2	US Army Aviators (1970)	43.4	43.9	44.7	45.4	46.7	48.1	49.5	50.8	51.6	52.7	53.5	10.1
3	US Army Men (1966)	42.7	43.4	44.3	45.1	46.4	47.9	49.4	51.0	51.9	53.0	53.8	11.1
4	USA Basic Trainees (1966)	42.8	43.4	44.4	45.2	46.5	47.9	49.4	50.7	51.6	52.6	53.3	10.5
5	USAF Flying Pers. (1950)	43.2	43.7	44.6	45.3	46.5	47.9	49.3	50.5	51.2	52.1	52.6	9.4
6	US Marine Corps (1966)	42.9	43.5	44.4	45.1	46.3	47.7	49.2	50.8	51.7	52.7	53.4	10.5
7	US Navy Recruits (1966)	42.9	43.4	44.2	45.0	46.2	47.6	49.1	50.4	51.3	52.4	53.1	10.2
8	US Army Men (1946)	42.2	42.9	43.9	44.7	46.0	47.5	49.0	50.3	51.1	52.1	52.8	10.6
9	US Army Women (1977)	38.7	39.2	40.0	40.7	41.9	43.4	45.0	46.6	47.5	48.5	49.2	10.5
10	US Army Women (1946)	37.3	37.9	38.9	39.7	41.0	42.4	43.7	44.9	45.7	46.7	47.4	10.1

Note. Percentiles in centimeters.

Table 7-12a. Statistical Values for Functional (Thumb-Tip) Reach
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	US Army Men (1966)	6680	82.60	0.06	4.85	0.04	5.87	65.6	100.2	34.6	.473
2	USA Basic Trainees (1966)	2638	82.25	0.09	4.65	0.06	5.66	65.2	100.2	35.0	.471
3	USAF Flying Pers. (1950)	4000	82.05	0.06	4.03	0.04	4.91	68.3	95.1	26.8	.467
4	US Navy Recruits (1966)	4089	81.49	0.07	4.66	0.05	5.71	66.5	97.5	32.0	.465
5	US Marine Corps (1966)	2008	80.33	0.11	4.79	0.08	5.97	66.5	96.4	29.9	.460
6	USAF Flying Pers. (1967)	2420	80.31	0.08	3.98	0.06	4.96	66.6	95.8	29.2	.453
7	US Navy Aviators (1964)	1549	80.03	0.09	3.61	0.06	4.51	69.2	92.2	23.0	.451
8	US Army Aviators (1970)	1482	79.34	0.11	4.12	0.08	5.20	66.7	94.3	27.6	.455
9	USAF Basic Trainees (1965)	2527	79.20	0.08	4.21	0.06	5.32	65.8	93.7	27.9	.452
10	USAF Women (1968)	1905	74.13	0.09	3.88	0.06	5.23	62.4	87.2	24.8	.457

Note. Values in centimeters.

Table 7-12b. Percentile Values for Functional (Thumb-Tip) Reach
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	US Army Men (1966)	71.9	73.1	74.9	76.5	79.3	82.4	85.8	89.0	90.9	93.1	94.6	22.7
2	USA Basic Trainees (1966)	71.7	72.9	74.7	76.4	79.1	82.2	85.3	88.2	90.1	92.3	93.8	22.1
3	USAF Flying Pers. (1950)	73.1	74.0	75.5	76.9	79.3	82.0	84.7	87.2	88.8	90.7	92.1	19.0
4	US Navy Recruits (1966)	70.9	72.1	74.0	75.6	78.3	81.4	84.5	87.5	89.3	91.4	92.8	21.9
5	US Marine Corps (1966)	69.6	70.9	72.7	74.3	77.0	80.2	83.5	86.6	88.6	90.8	92.3	22.7
6	USAF Flying Pers. (1967)	71.2	72.3	73.9	75.3	77.6	80.2	82.9	85.4	87.0	89.0	90.3	19.1
7	US Navy Aviators (1964)	72.5	73.3	74.5	75.6	77.4	79.8	82.4	84.9	86.5	88.1	89.2	16.7
8	US Army Aviators (1970)	70.9	71.8	73.1	74.3	76.4	79.1	82.0	84.9	86.8	89.0	90.5	19.6
9	USAF Basic Trainees (1965)	69.4	70.6	72.4	73.9	76.4	79.1	81.9	84.6	86.4	88.5	90.0	20.6
10	USAF Women (1968)	65.3	66.2	67.7	69.1	71.5	74.2	76.7	79.1	80.5	82.1	83.3	18.0

Note. Percentiles in centimeters.

Table 7-13a. Statistical Values for Shoulder (Bideltoid) Breadth (From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	48.24	0.05	2.56	0.04	5.31	40.0	56.7	16.7	.272
2	US Navy Aviators (1964)	1549	47.70	0.06	2.30	0.04	4.83	37.6	55.0	17.4	.269
3	US Army Aviators (1970)	1482	47.40	0.07	2.56	0.05	5.39	40.1	58.7	18.6	.272
4	USAF Basic Trainees (1965)	2527	45.78	0.05	2.48	0.03	5.42	38.0	54.4	16.4	.261
5	US Army Men (1946)	24,461	45.59	0.01	2.51	0.00	5.50	35.0	59.0	24.0	.262
6	US Marine Corps (1966)	2008	45.48	0.05	2.32	0.04	5.09	39.1	57.7	18.6	.261
7	USAF Flying Pers. (1950)	4000	45.41	0.04	2.27	0.03	5.00	37.5	53.7	16.2	.259
8	US Army Men (1966)	6682	45.37	0.03	2.54	0.02	5.59	36.7	58.4	21.7	.260
9	USA Basic Trainees (1966)	2639	45.08	0.05	2.47	0.03	5.48	36.2	54.2	18.0	.258
10	US Navy Recruits (1966)	4095	44.93	0.04	2.57	0.03	5.72	37.0	54.5	17.5	.256
11	US Army Women (1977)	1331	42.05	0.06	2.24	0.04	5.32	36.3	56.1	19.8	.258
12	USAF Women (1968)	1905	41.87	0.05	2.31	0.04	5.52	35.2	50.1	14.9	.258
13	US Army Women (1946)	8120	39.58	0.03	2.56	0.02	6.54	31.0	56.0	25.0	.244

Note. Values in centimeters.

Table 7-13b. Percentile Values for Shoulder (Bideltoid) Breadth
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	42.4	43.1	44.1	45.0	46.5	48.2	50.0	51.6	52.6	53.7	54.4	12.0
2	US Navy Aviators (1964)	42.1	42.9	43.9	44.8	46.2	47.7	49.2	50.6	51.5	52.4	53.1	11.0
3	US Army Aviators (1970)	41.8	42.3	43.2	44.1	45.6	47.4	49.1	50.7	51.6	52.7	53.5	11.7
4	USAF Basic Trainees (1965)	40.6	41.1	41.9	42.7	44.1	45.6	47.3	49.0	50.1	51.5	52.4	11.8
5	US Army Men (1946)	40.1	40.6	41.7	42.4	43.9	45.5	47.2	48.8	49.8	51.3	52.3	12.2
6	US Marine Corps (1966)	40.5	41.0	41.8	42.6	43.9	45.4	46.9	48.4	49.5	50.9	52.0	11.5
7	USAF Flying Pers. (1950)	40.4	41.0	41.8	42.6	43.8	45.3	46.9	48.4	49.3	50.3	50.9	10.5
8	US Army Men (1966)	40.0	40.6	41.5	42.3	43.6	45.2	47.0	48.6	49.8	51.1	52.1	12.1
9	USA Basic Trainees (1966)	39.6	40.3	41.2	42.0	43.4	45.0	46.7	48.3	49.4	50.5	51.2	11.6
10	US Navy Recruits (1966)	39.2	40.0	40.9	41.8	43.2	44.8	46.6	48.3	49.4	50.6	51.4	12.2
11	US Army Women (1977)	37.3	37.7	38.4	39.2	40.5	42.0	43.5	44.8	45.7	46.7	47.5	10.2
12	USAF Women (1968)	36.7	37.3	38.2	39.0	40.3	41.8	43.3	44.9	45.9	47.1	48.0	11.3
13	US Army Women (1946)	34.2	34.9	35.8	36.6	37.8	39.3	41.1	43.0	44.2	45.6	46.7	12.5

Note. Percentiles in centimeters.

Table 7-14a. Statistical Values for Hip Breadth, Sitting
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	US Army Aviators (1970)	1482	37.80	0.07	2.72	0.05	7.19	30.8	48.5	17.7	.217
2	USAF Flying Pers. (1967)	2420	37.79	0.05	2.30	0.03	6.09	31.2	47.8	16.6	.213
3	US Navy Aviators (1964)	1549	36.80	0.06	2.17	0.04	5.90	30.4	45.4	15.0	.207
4	USAF Flying Pers. (1950)	4000	35.46	0.03	2.15	0.02	6.06	29.3	44.6	15.3	.202
5	US Army Men (1946)	24,575	35.44	0.01	2.28	0.00	6.43	28.5	50.5	22.0	.204
6	USAF Basic Trainees (1965)	2527	35.27	0.05	2.52	0.04	7.14	28.4	45.9	17.5	.201
7	US Marine Corps (1966)	2008	34.16	0.04	2.02	0.03	5.90	28.8	43.1	14.3	.196
8	US Army Men (1966)	6682	34.16	0.03	2.38	0.02	6.97	26.6	60.0	23.4	.196
9	USA Basic Trainees (1966)	2639	33.92	0.05	2.36	0.03	6.95	27.8	47.7	19.9	.194
10	US Navy Recruits (1966)	4094	33.85	0.04	2.36	0.03	6.97	27.5	45.2	17.7	.193
11	US Army Women (1977)[a]	255	38.27	0.20	3.27	0.14	8.54	30.1	47.8	17.7	.235
12	USAF Women (1968)[a]	1905	38.19	0.07	2.86	0.05	7.49	29.1	50.2	21.1	.236
13	US Army Women (1946)	8120	36.92	0.03	2.83	0.02	7.76	27.0	50.0	23.0	.228

Note. Values in centimeters.

[a] Thigh-to-thigh breadth, sitting.

Table 7-14b. Percentile Values for Hip Breadth, Sitting

(From DoD-HDBK-743 [Metric], 1980.)

							Median						Range
No.	Group (Year)	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	(1st-99th)
1	US Army Aviators (1970)	32.1	32.6	33.5	34.4	35.9	37.7	39.6	41.4	42.4	43.7	44.5	12.4
2	USAF Flying Pers. (1967)	32.7	33.3	34.2	34.9	36.2	37.7	39.3	40.8	41.8	42.9	43.8	11.1
3	US Navy Aviators (1964)	32.2	32.6	33.3	34.0	35.3	36.8	38.2	39.6	40.4	41.4	42.2	10.0
4	USAF Flying Pers. (1950)	30.9	31.4	32.1	32.8	34.0	35.4	36.9	38.3	39.2	40.3	41.0	10.1
5	US Army Men (1946)	31.0	31.5	32.3	32.8	34.0	35.3	36.8	38.4	39.4	41.1	42.4	11.4
6	USAF Basic Trainees (1965)	30.5	31.0	31.8	32.4	33.5	34.9	36.7	38.7	40.1	41.7	42.9	12.4
7	US Marine Corps (1966)	30.0	30.4	31.1	31.8	32.8	34.0	35.4	36.8	37.7	38.8	39.7	9.7
8	US Army Men (1966)	29.5	30.0	30.7	31.4	32.5	33.9	35.6	37.3	38.4	39.8	40.7	11.2
9	USA Basic Trainees (1966)	29.2	29.7	30.4	31.1	32.2	33.7	35.4	37.1	38.2	39.4	40.1	10.9
10	US Navy Recruits (1966)	29.3	29.8	30.5	31.1	32.2	33.6	35.3	37.0	38.2	39.5	40.3	11.0
11	US Army Women (1977)[a]	31.6	32.1	33.0	34.0	36.0	38.2	40.4	42.5	43.9	45.7	47.1	15.5
12	USAF Women (1968)[a]	32.1	32.8	33.8	34.7	36.2	38.0	40.0	42.0	43.3	44.8	45.9	13.8
13	US Army Women (1946)	31.1	31.7	32.7	33.5	35.0	36.7	38.6	40.6	42.0	43.6	44.9	13.8

Note. Percentiles in centimeters.

[a] Thigh-to-thigh breadth, sitting.

Table 7-15a. Statistical Values for Head Length
(From DoD-HDBK-743 [Metric], 1980.)

								Range			Stature
No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Min.	Max.	Total	ratio
1	USAF Flying Pers. (1967)	2420	19.87	0.01	0.67	0.01	3.39	17.5	22.6	5.1	.112
2	US Navy Aviators (1964)	1549	19.83	0.02	0.66	0.01	3.32	17.8	22.0	4.2	.112
3	USAF Flying Pers. (1950)	4000	19.70	0.01	0.64	0.01	3.25	17.5	22.3	4.8	.112
4	US Army Aviators (1970)	1482	19.70	0.02	0.67	0.01	3.39	17.0	21.7	4.7	.113
5	USAF Basic Trainees (1965)	2527	19.53	0.01	0.72	0.01	3.69	17.0	22.2	5.2	.112
6	CWS Face Study (1945)	3075	19.50	0.01	0.69	0.01	3.55	16.5	21.8	5.3	.112
7	US Army Men (1946)	24,471	19.47	0.00	0.70	0.00	3.60	15.5	23.0	7.5	.112
8	US Army Men (1966)	6682	19.47	0.01	0.73	0.01	3.77	16.7	22.3	5.6	.112
9	US Marine Corps (1966)	2008	19.43	0.02	0.72	0.01	3.73	16.9	22.1	5.2	.111
10	US Navy Recruits (1966)	4095	19.42	0.01	0.72	0.01	3.71	16.8	21.9	5.1	.111
11	USA Basic Trainees (1966)	2639	19.41	0.01	0.72	0.01	3.69	16.6	21.8	5.2	.111
12	US Army Women (1977)	1331	18.71	0.02	0.67	0.01	3.58	16.2	20.8	4.6	.115
13	USAF Women (1968)	1905	18.41	0.02	0.68	0.01	3.69	16.4	20.7	4.3	.114
14	US Army Women (1946)	8118	18.36	0.01	0.65	0.01	3.54	15.8	20.5	4.7	.113
15	USAF WAF Trainees (1952)	847	17.38	0.03	0.75	0.02	4.31	15.1	19.8	4.7	.107

__Note.__ Values in centimeters.

Table 7-15b. Percentile Values for Head Length
(From DoD-HDBK-743 [Metric], 1980.)

							Median						Range
No.	Group (Year)	1st	2nd	5th	10th	25th	50th	75th	90th	95th	98th	99th	(1st-99th)
1	USAF Flying Pers. (1967)	18.3	18.5	18.8	19.0	19.4	19.9	20.3	20.7	21.0	21.3	21.5	3.2
2	US Navy Aviators (1964)	18.3	18.5	18.8	19.0	19.4	19.8	20.3	20.7	20.9	21.2	21.4	3.1
3	USAF Flying Pers. (1950)	18.2	18.4	18.7	18.9	19.3	19.7	20.1	20.5	20.8	21.0	21.2	3.0
4	US Army Aviators (1970)	18.0	18.3	18.6	18.8	19.3	19.7	20.2	20.6	20.8	21.0	21.1	3.1
5	USAF Basic Trainees (1965)	17.9	18.1	18.4	18.6	19.0	19.5	20.0	20.5	20.7	21.0	21.2	3.3
6	US Army Men (1966)	17.8	18.0	18.2	18.5	19.0	19.5	20.0	20.4	20.7	21.0	21.2	3.4
7	US Army Men (1946)	17.8	18.0	18.3	18.6	19.0	19.5	20.0	20.4	20.6	20.9	21.2	3.4
8	US Marine Corps (1966)	17.8	18.0	18.2	18.5	18.9	19.4	19.9	20.4	20.6	20.9	21.1	3.3
9	US Navy Recruits (1966)	17.7	17.9	18.2	18.5	18.9	19.4	19.9	20.4	20.6	20.9	21.1	3.4
10	USA Basic Trainees (1966)	17.7	17.9	18.2	18.5	18.9	19.4	19.9	20.3	20.6	20.9	21.1	3.4
11	CWS Face Study (1945)	17.7	17.9	18.2	18.5	18.9	19.4	19.8	20.2	20.5	20.8	20.9	3.2
12	US Army Women (1977)	17.1	17.3	17.6	17.9	18.3	18.7	19.2	19.6	19.8	20.1	20.3	3.2
13	USAF Women (1968)	16.8	17.0	17.3	17.5	18.0	18.4	18.9	19.3	19.5	19.8	20.0	3.2
14	US Army Women (1946)	16.9	17.0	17.3	17.5	17.9	18.4	18.8	19.2	19.4	19.7	19.9	3.0
15	USAF WAF Trainees (1952)	15.5	15.8	16.2	16.5	16.9	17.4	17.9	18.4	18.6	18.8	19.0	3.5

Note. Percentiles in centimeters.

Table 7-16a. Statistical Values for Head Breadth
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	15.60	0.01	0.54	0.01	3.48	13.9	17.6	3.7	.088
2	US Navy Aviators (1964)	1549	15.57	0.01	0.53	0.01	3.39	13.6	17.2	3.6	.088
3	USAF Flying Pers. (1950)	4000	15.41	0.01	0.51	0.01	3.31	13.6	17.2	3.6	.088
4	CWS Face Study (1945)	3075	15.28	0.01	0.56	0.01	3.68	13.4	17.5	4.1	.088
5	US Marine Corps (1966)	2008	15.28	0.01	0.57	0.01	3.74	13.0	17.4	4.4	.088
6	US Army Aviators (1970)	1482	15.27	0.01	0.54	0.01	3.54	13.4	17.2	3.8	.087
7	USA Basic Trainees (1966)	2639	15.27	0.01	0.57	0.01	3.70	13.2	17.4	4.2	.087
8	US Army Men (1966)	6682	15.27	0.01	0.59	0.01	3.83	12.9	17.4	4.5	.088
9	US Navy Recruits (1966)	4095	15.23	0.01	0.57	0.01	3.76	13.3	17.3	4.0	.087
10	USAF Basic Trainees (1965)	2527	15.21	0.01	0.57	0.01	3.75	13.4	17.4	4.0	.087
11	US Army Men (1946)	24,447	15.21	0.01	0.59	0.00	3.88	12.5	18.0	5.5	.087
12	US Army Women (1977)	1331	14.61	0.01	0.54	0.01	3.69	13.0	16.5	3.5	.090
13	US Army Women (1946)	8118	14.56	0.01	0.55	0.00	3.76	12.4	16.7	4.3	.090
14	USAF Women (1968)	1905	14.52	0.01	0.59	0.01	4.06	12.7	17.1	4.4	.090
15	USAF WAF Trainees (1952)	847	14.49	0.02	0.50	0.01	3.45	13.1	16.4	3.3	.089

Note. Values in centimeters.

Table 7-16b. Percentile Values for Head Breadth
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	14.4	14.5	14.7	14.9	15.2	15.6	16.0	16.3	16.5	16.8	16.9	2.5
2	US Navy Aviators (1964)	14.3	14.5	14.7	14.9	15.2	15.6	15.9	16.2	16.4	16.6	16.8	2.5
3	USAF Flying Pers. (1950)	14.3	14.4	14.6	14.8	15.1	15.4	15.7	16.1	16.3	16.5	16.7	2.4
4	USA Basic Trainees (1966)	14.0	14.1	14.4	14.6	14.9	15.3	15.6	16.0	16.2	16.5	16.7	2.7
5	US Marine Corps (1966)	14.0	14.1	14.4	14.6	14.9	15.3	15.6	16.0	16.2	16.5	16.6	2.6
6	US Army Aviators (1970)	14.1	14.2	14.4	14.6	14.9	15.3	15.6	16.0	16.2	16.4	16.6	2.5
7	US Army Men (1966)	13.9	14.1	14.3	14.6	14.9	15.2	15.6	16.0	16.3	16.5	16.7	2.8
8	US Army Men (1946)	13.8	14.0	14.3	14.5	14.8	15.2	15.6	16.0	16.2	16.5	16.7	2.9
9	US Navy Recruits (1966)	14.0	14.1	14.3	14.5	14.8	15.2	15.6	16.0	16.2	16.5	16.6	2.6
10	USAF Basic Trainees (1965)	14.0	14.1	14.3	14.5	14.8	15.2	15.6	16.0	16.2	16.4	16.6	2.6
11	CWS Face Study (1945)	13.8	14.0	14.2	14.4	14.8	15.1	15.5	15.8	16.1	16.4	16.6	2.8
12	US Army Women (1977)	13.4	13.6	13.8	13.9	14.2	14.6	15.0	15.3	15.6	15.8	16.1	2.7
13	US Army Women (1946)	13.2	13.4	13.7	13.9	14.2	14.6	14.9	15.2	15.4	15.7	15.9	2.7
14	USAF Women (1968)	13.1	13.3	13.5	13.8	14.1	14.5	14.9	15.3	15.5	15.8	16.0	2.9
15	USAF WAF Trainees (1952)	13.4	13.5	13.7	13.8	14.1	14.5	14.8	15.2	15.4	15.6	15.8	2.4

Note. Percentiles in centimeters.

Table 7-17a. Statistical Values for Hand Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Men's Hands (1968)	148	19.72	0.08	0.93	0.05	4.73	17.3	22.8	5.5	
2	USAF Basic Trainees (1965)	2527	19.68	0.02	1.01	0.01	5.13	16.0	23.8	7.8	.112
3	US Army Men (1946)	24,487	19.25	0.00	0.93	0.00	4.83	15.0	23.0	8.0	.111
4	US Army Aviators (1970)	1482	19.20	0.02	0.87	0.02	4.55	16.3	22.3	6.0	.110
5	US Navy Aviators (1964)	1549	19.12	0.02	0.86	0.02	4.50	16.4	22.8	6.4	.108
6	USAF Flying Pers. (1967)	2420	19.11	0.02	0.82	0.01	4.29	16.7	22.2	5.5	.108
7	USA Basic Trainees (1966)	2639	19.05	0.02	0.91	0.01	4.79	16.4	23.5	7.1	.109
8	US Army Men (1966)	6682	19.03	0.01	0.96	0.01	5.06	15.5	23.5	8.0	.109
9	USAF Flying Pers. (1950)	4000	19.02	0.01	0.85	0.01	4.47	14.9	22.2	7.3	.108
10	US Marine Corps (1966)	2008	18.94	0.02	0.93	0.01	4.91	15.2	22.2	7.0	.108
11	US Navy Recruits (1966)	4095	18.90	0.01	0.90	0.01	4.78	15.3	22.0	6.7	.108
12	USAF Women (1968)	1905	18.38	0.02	0.96	0.02	5.22	15.3	22.0	6.7	.113
13	USAF Women's Hands (1968)	211	17.93	0.06	0.86	0.04	4.79	15.7	20.5	4.8	.110
14	US Army Women (1946)	8113	17.49	0.01	0.82	0.01	4.70	14.7	20.8	6.1	.108
15	US Army Women (1977)	1331	17.44	0.02	0.90	0.02	5.17	14.9	20.4	5.5	.107
16	USAF WAF Trainees (1952)	851	17.17	0.03	0.88	0.02	5.10	14.9	20.7	5.8	.106

Note. Values in centimeters.

Table 7-17b. Percentile Values for Hand Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Basic Trainees (1965)	17.4	17.6	18.0	18.4	19.0	19.7	20.3	21.0	21.4	21.9	22.3	4.9
2	USAF Men's Hands (1968)			18.3	18.6	19.1	19.6	20.4	21.0	21.2			
3	US Army Men (1946)	17.1	17.4	17.8	18.1	18.6	19.2	19.8	20.4	20.8	21.2	21.5	4.4
4	US Army Aviators (1970)	17.2	17.4	17.8	18.1	18.6	19.2	19.8	20.3	20.7	21.1	21.5	4.3
5	US Navy Aviators (1964)	17.3	17.4	17.7	18.0	18.5	19.1	19.7	20.2	20.6	20.9	21.1	3.8
6	USAF Flying Pers. (1967)	17.3	17.5	17.8	18.1	18.5	19.1	19.7	20.2	20.5	20.9	21.1	3.8
7	US Army Men (1966)	16.9	17.2	17.5	17.8	18.4	19.0	19.6	20.3	20.7	21.1	21.4	4.5
8	USA Basic Trainees (1966)	17.0	17.2	17.6	17.9	18.4	19.0	19.7	20.2	20.6	21.0	21.3	4.3
9	USAF Flying Pers. (1950)	17.1	17.3	17.6	17.9	18.4	19.0	19.6	20.1	20.5	20.8	21.0	3.9
10	US Marine Corps (1966)	16.8	17.1	17.5	17.8	18.3	18.9	19.5	20.2	20.6	21.0	21.3	4.5
11	US Navy Recruits (1966)	16.8	17.1	17.4	17.8	18.3	18.9	19.5	20.1	20.4	20.9	21.2	4.4
12	USAF Women (1968)	16.4	16.6	16.9	17.2	17.7	18.3	19.0	19.7	20.1	20.5	20.8	4.4
13	USAF Women's Hands (1968)	16.2	16.3	16.5	16.8	17.3	17.9	18.6	19.1	19.3	19.5	19.6	3.4
14	US Army Women (1946)	15.5	15.8	16.1	16.4	16.9	17.5	18.0	18.6	18.9	19.3	19.6	4.1
15	US Army Women (1977)	15.5	15.7	16.1	16.3	16.8	17.4	18.0	18.7	19.0	19.4	19.6	4.1
16	USAF WAF Trainees (1952)	15.3	15.5	15.8	16.0	16.5	17.2	17.8	18.3	18.6	19.0	19.4	4.1

Note. Percentiles in centimeters.

Table 7-18a. Statistical Values for Hand Breadth
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	 Max.	 Total	Stature ratio
1	USAF Men's Hands (1968)	148	8.96	0.03	0.40	0.02	4.51	7.6	10.0	2.4	
2	US Navy Aviators (1964)	1549	8.96	0.01	0.43	0.01	4.75	7.6	10.2	2.6	.050
3	US Navy Recruits (1966)	4095	8.96	0.01	0.58	0.01	6.49	7.1	10.9	3.8	.051
4	USAF Flying Pers. (1967)	2420	8.90	0.01	0.41	0.01	4.66	7.6	10.2	2.6	.050
5	US Army Men (1966)	6681	8.90	0.01	0.49	0.00	5.52	7.1	10.7	3.6	.051
6	USA Basic Trainees (1966)	2629	8.88	0.01	0.46	0.01	5.18	7.2	10.7	3.5	.051
7	US Marine Corps (1966)	2008	8.86	0.01	0.44	0.01	4.98	7.7	10.9	3.2	.051
8	USAF Basic Trainees (1965)	2527	8.86	0.01	0.48	0.01	5.42	7.4	10.5	3.1	.051
9	US Army Aviators (1970)	1482	8.85	0.01	0.42	0.01	4.71	7.7	10.3	2.6	.051
10	USAF Flying Pers. (1950)	4000	8.83	0.01	0.41	0.00	4.64	7.6	10.2	2.6	.050
11	US Army Men (1946)	24,488	8.67	0.00	0.48	0.00	5.54	6.0	11.0	5.0	.050
12	US Army Women (1977)	1331	7.82	0.01	0.39	0.01	4.97	6.6	9.1	2.5	.048
13	USAF Women's Hands (1968)	211	7.71	0.03	0.38	0.02	4.87	6.9	8.7	1.8	.047
14	US Army Women (1946)	8113	7.69	0.01	0.51	0.00	6.57	6.3	9.9	3.6	.047
15	USAF WAF Trainees (1952)	851	7.66	0.02	0.49	0.01	6.42	6.3	9.6	3.3	.047
16	USAF Women (1968)	1905	7.55	0.01	0.39	0.01	5.17	6.1	8.8	2.7	.047

Note. Values in centimeters.

Table 7-18b. Percentile Values for Hand Breadth
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	US Navy Aviators (1964)	8.0	8.1	8.2	8.4	8.7	9.0	9.2	9.5	9.7	9.8	10.0	2.0
2	US Navy Recruits (1966)	7.7	7.9	8.1	8.2	8.5	8.9	9.4	9.7	10.0	10.2	10.3	2.6
3	USAF Men's Hands (1968)			8.3	8.5	8.7	8.9	9.2	9.5	9.7			
4	US Army Men (1966)	7.8	7.9	8.1	8.3	8.6	8.9	9.2	9.5	9.7	10.0	10.1	2.3
5	USA Basic Trainees (1966)	7.9	8.0	8.2	8.3	8.6	8.9	9.2	9.5	9.7	9.9	10.0	2.1
6	USAF Basic Trainees (1965)	7.7	7.9	8.1	8.2	8.5	8.9	9.2	9.5	9.7	9.8	10.0	2.3
7	USAF Flying Pers. (1967)	8.0	8.1	8.2	8.4	8.6	8.9	9.2	9.4	9.6	9.8	9.9	1.9
8	US Marine Corps (1966)	7.9	8.0	8.2	8.3	8.6	8.8	9.2	9.4	9.6	9.8	9.9	2.0
9	US Army Aviators (1970)	8.0	8.0	8.2	8.3	8.6	8.8	9.1	9.4	9.5	9.7	9.9	1.9
10	USAF Flying Pers. (1950)	7.9	8.0	8.2	8.3	8.6	8.8	9.1	9.4	9.5	9.7	9.8	1.9
11	US Army Men (1946)	7.5	7.6	7.8	8.0	8.3	8.7	9.0	9.3	9.5	9.7	9.9	2.4
12	US Army Women (1977)	7.0	7.0	7.2	7.3	7.6	7.8	8.1	8.3	8.5	8.6	8.7	1.7
13	USAF Women's Hands (1968)	6.8	6.9	7.1	7.2	7.4	7.7	8.0	8.2	8.3	8.5	8.6	1.8
14	US Army Women (1946)	6.7	6.8	7.0	7.1	7.3	7.6	8.0	8.4	8.6	9.0	9.2	2.5
15	USAF WAF Trainees (1952)	6.6	6.7	6.9	7.0	7.3	7.6	8.0	8.3	8.5	8.8	9.0	2.4
16	USAF Women (1968)	6.7	6.8	6.9	7.1	7.3	7.6	7.8	8.1	8.2	8.4	8.5	1.8

Note. Percentiles in centimeters.

Table 7-19a. Statistical Values for Foot Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	USAF Flying Pers. (1967)	2420	27.05	0.02	1.19	0.02	4.40	23.2	31.3	8.1	.152
2	USA Basic Trainees (1966)	2639	26.85	0.02	1.26	0.02	4.70	22.2	31.8	9.6	.154
3	Ft. Knox Foot Study (1946)	5574	26.84	0.02	1.16	0.01	4.32	22.9	31.5	8.6	.155
4	USAF Basic Trainees (1965)	2527	26.78	0.03	1.29	0.02	4.82	22.6	31.7	9.1	.153
5	US Army Men (1966)	6682	26.78	0.02	1.30	0.01	4.86	21.4	32.3	10.9	.153
6	US Marine Corps (1966)	2008	26.70	0.03	1.29	0.02	4.84	22.5	31.3	8.8	.153
7	USAF Flying Pers. (1950)	4000	26.68	0.02	1.15	0.01	4.31	22.5	31.1	8.6	.152
8	US Navy Aviators (1964)	1549	26.62	0.03	1.20	0.02	4.52	23.0	30.4	7.4	.150
9	US Army Men (1946)	24,372	26.51	0.00	1.21	0.00	4.74	21.0	30.5	9.5	.152
10	US Navy Recruits (1966)	4095	26.51	0.02	1.29	0.01	4.87	22.1	31.3	9.2	.151
11	US Army Aviators (1970)	1482	26.49	0.03	1.27	0.02	4.78	21.5	30.7	9.2	.152
12	US Army Women (1977)	1331	24.32	0.03	1.25	0.02	5.14	20.9	29.8	8.9	.149
13	USAF Women (1968)	1905	24.07	0.03	1.13	0.02	4.69	21.0	27.6	6.6	.148
14	USAF WAF Trainees (1952)	850	23.94	0.04	1.17	0.03	4.89	20.3	29.0	8.7	.147
15	US Army Women (1946)	3321	23.93	0.02	1.11	0.01	4.62	20.0	27.9	7.9	.148

Note. Values in centimeters.

Table 7-19b. Percentile Values for Foot Length
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	USAF Flying Pers. (1967)	24.3	24.7	25.1	25.5	26.2	27.0	27.8	28.6	29.0	29.6	29.9	5.6
2	Ft. Knox Foot Study (1946)	24.2	24.5	25.0	25.4	26.1	26.9	27.7	28.4	28.8	29.3	29.6	5.4
3	USA Basic Trainees (1966)	24.0	24.3	24.8	25.2	26.0	26.8	27.7	28.4	29.0	29.6	30.1	6.1
4	USAF Basic Trainees (1965)	23.8	24.1	24.7	25.1	25.9	26.8	27.6	28.4	28.9	29.5	29.9	6.1
5	US Army Men (1966)	23.8	24.2	24.7	25.1	25.9	26.7	27.6	28.4	29.0	29.6	30.0	6.2
6	US Marine Corps (1966)	23.9	24.2	24.6	25.1	25.8	26.7	27.5	28.4	28.9	29.5	30.0	6.1
7	USAF Flying Pers. (1950)	24.1	24.3	24.8	25.2	25.9	26.7	27.4	28.1	28.6	29.1	29.5	5.4
8	US Navy Aviators (1964)	24.0	24.3	24.7	25.1	25.8	26.6	27.4	28.2	28.7	29.2	29.5	5.5
9	US Navy Recruits (1966)	23.6	23.9	24.4	24.8	25.6	26.5	27.4	28.2	28.7	29.3	29.7	6.1
10	US Army Aviators (1970)	23.6	23.9	24.4	24.9	25.6	26.5	27.4	28.1	28.6	29.1	29.4	5.8
11	US Army Men (1946)	23.6	24.0	24.5	24.9	25.7	26.5	27.4	28.1	28.6	29.0	29.3	5.7
12	US Army Women (1977)	21.6	21.9	22.3	22.8	23.4	24.3	25.1	26.0	26.5	27.1	27.5	5.9
13	USAF Women (1968)	21.5	21.8	22.2	22.6	23.3	24.1	24.8	25.6	26.0	26.5	26.8	5.3
14	USAF WAF Trainees (1952)	21.4	21.7	22.2	22.6	23.2	24.0	24.7	25.4	25.8	26.3	26.6	5.2
15	US Army Women (1946)	21.5	21.8	22.2	22.6	23.2	23.9	24.6	25.4	25.8	26.4	26.7	5.2

Note. Percentiles in centimeters.

Table 7-20a. Statistical Values for Foot Breadth (From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	N	Mean	SE(M)	S.D.	SE(S.D.)	V(%)	Range Min.	Range Max.	Range Total	Stature ratio
1	US Navy Aviators (1964)	1549	10.24	0.02	0.77	0.01	7.54	8.4	13.0	4.6	.058
2	US Army Aviators (1970)	1482	9.99	0.02	0.61	0.01	6.07	8.2	12.8	4.6	.057
3	USA Basic Trainees (1966)	2639	9.92	0.01	0.54	0.01	5.48	8.2	11.9	3.7	.057
4	US Army Men (1966)	6682	9.84	0.01	0.55	0.00	5.56	8.0	12.2	4.2	.056
5	USAF Basic Trainees (1965)	2527	9.83	0.01	0.55	0.01	5.60	8.0	12.0	4.0	.056
6	US Army Men (1946)	24,466	9.82	0.00	0.63	0.00	6.42	6.5	13.0	6.5	.056
7	Ft. Knox Foot Study (1946)	5561	9.80	0.01	0.52	0.00	5.31	8.0	11.6	3.6	.056
8	US Marine Corps (1966)	2008	9.80	0.01	0.52	0.01	5.32	8.2	11.8	3.6	.056
9	USAF Flying Pers. (1967)	2420	9.77	0.01	0.50	0.01	5.07	8.4	11.7	3.3	.055
10	US Navy Recruits (1966)	4095	9.76	0.01	0.53	0.01	5.40	8.2	12.1	3.9	.056
11	USAF Flying Pers. (1950)	4000	9.65	0.01	0.47	0.01	4.87	8.1	11.6	3.5	.055
12	USAF WAF Trainees (1952)	849	9.09	0.02	0.53	0.01	5.82	7.6	11.0	3.4	.056
13	US Army Women (1946)	3324	9.05	0.01	0.57	0.01	6.27	7.3	11.2	3.9	.056
14	USAF Women (1968)	1905	8.87	0.01	0.50	0.01	5.64	7.0	11.0	4.0	.055
15	US Army Women (1977)	1331	8.87	0.01	0.52	0.01	5.81	7.5	10.8	3.3	.054

Note. Values in centimeters.

Table 7-20b. Percentile Values for Foot Breadth
(From DoD-HDBK-743 [Metric], 1980.)

No.	Group (Year)	1st	2nd	5th	10th	25th	Median 50th	75th	90th	95th	98th	99th	Range (1st-99th)
1	US Navy Aviators (1964)	8.8	8.9	9.1	9.3	9.7	10.2	10.7	11.3	11.6	12.0	12.3	3.5
2	US Army Aviators (1970)	8.7	8.8	9.0	9.2	9.6	10.0	10.4	10.8	11.0	11.3	11.5	2.8
3	USA Basic Trainees (1966)	8.8	8.9	9.1	9.2	9.6	9.9	10.3	10.6	10.8	11.1	11.3	2.5
4	US Army Men (1946)	8.3	8.5	8.8	9.0	9.4	9.8	10.2	10.6	10.8	11.1	11.3	3.0
5	US Army Men (1966)	8.6	8.8	9.0	9.2	9.5	9.8	10.2	10.6	10.8	11.0	11.2	2.6
6	USAF Basic Trainees (1965)	8.6	8.8	9.0	9.1	9.5	9.8	10.2	10.6	10.8	11.0	11.2	2.6
7	US Marine Corps (1966)	8.6	8.7	9.0	9.2	9.4	9.8	10.1	10.5	10.7	10.9	11.1	2.5
8	USAF Flying Pers. (1967)	8.7	8.8	9.0	9.2	9.4	9.8	10.1	10.4	10.6	10.9	11.0	2.3
9	Ft. Knox Foot Study (1946)	8.6	8.7	9.0	9.1	9.4	9.8	10.2	10.4	10.6	10.8	11.0	2.4
10	US Navy Recruits (1966)	8.6	8.8	8.9	9.1	9.4	9.7	10.1	10.4	10.7	10.9	11.1	2.5
11	USAF Flying Pers. (1950)	8.6	8.7	8.9	9.1	9.3	9.6	10.0	10.3	10.4	10.7	10.8	2.2
12	USAF WAF Trainees (1952)	7.9	8.0	8.2	8.4	8.8	9.1	9.5	9.8	9.9	10.1	10.2	2.3
13	US Army Women (1946)	7.8	7.9	8.2	8.3	8.7	9.0	9.4	9.8	10.0	10.3	10.4	2.6
14	USAF Women (1968)	7.7	7.8	8.0	8.2	8.5	8.9	9.2	9.6	9.8	10.0	10.2	2.5
15	US Army Women (1977)	7.7	7.8	8.0	8.2	8.5	8.8	9.2	9.5	9.7	10.0	10.2	2.5

Note. Percentiles in centimeters.

7.4 Arm Reach Data

7.4.1 Data Source

The arm reach data used here originated from Kennedy for both men (Kennedy, 1964) and women (Kennedy, 1976). The male arm reach data were obtained by Kennedy on 20 subjects selected to be anthropometrically representative of the Air Force male population. The female data were obtained on 30 subjects selected to be anthropometrically equivalent to the Air Force female population. The measurements were taken with the subjects on a hard, unyielding seat with a backrest angle of 103° and a seat angle of 6°. The reach task required the subjects to grasp a small knob between the thumb and forefinger of the right hand and push away until the arm was fully extended while the shoulders were in continuous contact with the seat back. The subjects wore light indoor clothing that would not restrict their reach. Reaches were made to a series of vertical planes emanating from the seat reference point (the intersection of the planes of the seat and backrest surfaces at the seat midline), starting at 0°, or straight ahead, and at 15° increments to the right and left to 180°, or directly behind. At each of these angles, reaches were made to a series of horizontal planes at sequential intervals (5 in. for men and 6 in. for women) starting at the seat reference point to 45 in. for men and 42 in. for women above this point.

7.4.2 Data Tables

The body dimensions of the male and female subjects measured by Kennedy are depicted in Table 7-21. The arm reach data for the men are presented in Tables 7-22 through 7-31, and the data for the women are contained in Tables 7-32 through 7-39. The original data were measured to the nearest quarter of an inch and are here rounded down to the nearest tenth of an inch and converted to centimeters. The tables were adapted from Webb Associates (1978).

Table 7-21. Anthropometric Dimensions of the Male and Female Subjects in Arm Reach Measurements (From Webb Associates, 1978.)

	Males[a]				Females[b]			
Dimension	Mean		S.D.		Mean		S.D.	
Age (years)		(27.9)		(5.1)		(20.8)		(4.03)
Stature	176.8	(69.6)	6.7	(2.63)	162.8	(64.1)	5.74	(2.26)
Weight	75.2	(165.8)	9.35	(20.62)	56.37	(124.3)	5.56	(12.26)
Sitting height	92.2	(36.3)	3.45	(1.36)	86.4	(34.0)	2.64	(1.04)
Eye height, sitting	-		-		73.7	(29.0)	2.64	(1.04)
Acromion height, sitting	61.5	(24.2)	3.05	(1.20)	55.6	(21.9)	2.51	(0.99)
Functional reach	81.3	(32.0)	3.86	(1.52)	71.9	(28.3)	3.53	(1.39)
Arm reach from wall	86.9	(34.2)	3.63	(1.43)	-		-	
Maximum reach from wall	97.0	(38.2)	3.91	(1.54)	-		-	
Shoulder-elbow length	36.6	(14.4)	1.57	(0.62)	32.5	(12.8)	1.68	(0.66)
Forearm-hand length	48.3	(19.0)	1.88	(0.74)	42.4	(16.7)	1.98	(0.78)
Hand length	19.3	(7.6)	0.58	(0.23)	-		-	
Buttock-knee length	-		-		57.4	(22.6)	2.16	(0.85)
Biacromial breadth	39.9	(15.7)	1.91	(0.75)	36.3	(14.3)	1.55	(0.61)
Shoulder breadth	-		-		41.9	(16.5)	1.98	(0.78)

Note. Data given in centimeters and kilograms with inches and pounds in parentheses.

[a] 20 subjects measured.

[b] 30 subjects measured.

Table 7-22. Men's Right-Hand Grasping Reach to a Plane through the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles					
			5		50		95	
L 165								
L 150								
L 135								
L 120								
L 105								
L 90								
L 75								
L 60								
L 45								
L 30								
L 15								
0								
R 15								
R 30			44.5	(17.5)	52.6	(20.7)	63.5	(25.0)
R 45	41.1	(16.2)	49.5	(19.5)	55.1	(21.7)	66.0	(26.0)
R 60	44.5	(17.4)	52.1	(20.5)	56.4	(22.2)	66.5	(26.2)
R 75	43.7	(17.2)	50.8	(20.0)	56.4	(22.2)	66.0	(26.0)
R 90	43.2	(17.0)	49.5	(19.5)	56.4	(22.2)	64.8	(25.5)
R 105	41.1	(16.2)	47.5)	(18.7)	55.9	(22.0)	64.0	(25.2)
R 120	38.1	(15.0)	46.2	(18.2)	52.6	(20.7)	62.2	(24.5)
R 135	33.0	(13.0)	41.9	(16.5)	48.3	(19.0)	59.7	(23.5)
R 150			35.6	(14.0)	41.9	(16.5)	51.3	(20.2)
R 165					33.0	(13.0)	43.2	(17.0)
180								

Note. Data given in centimeters with inches in parentheses.

Table 7-23. Men's Right-Hand Grasping Reach to a Horizontal Plane 12.5 cm (5 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles		
		5	50	95
L 165				
L 150				
L 135				
L 120				
L 105				
L 90				
L 75				
L 60				
L 45				
L 30				
L 15				
R 30	55.9 (22.0)	60.2 (23.7)	66.0 (26.0)	74.9 (29.5)
R 45	59.7 (23.5)	64.0 (25.2)	69.1 (27.2)	76.2 (30.0)
R 60	60.2 (23.7)	65.3 (25.7)	70.4 (27.7)	76.2 (30.0)
R 75	61.0 (24.0)	65.3 (25.7)	69.9 (27.5)	76.7 (30.2)
R 90	61.0 (24.0)	65.3 (25.7)	69.9 (27.5)	78.0 (30.7)
R 105	60.2 (23.7)	64.0 (25.2)	68.6 (27.0)	76.2 (30.0)
R 120	58.4 (23.0)	62.2 (24.5)	67.3 (26.5)	73.7 (29.0)
R 135	54.6 (21.5)	57.7 (22.7)	63.5 (25.0)	71.1 (28.0)
R 150			56.4 (22.2)	65.3 (25.7)
R 165			48.8 (19.2)	53.8 (21.2)
180				

Note. Data given in centimeters with inches in parentheses.

Table 7-24. Men's Right-Hand Grasping Reach to a Horizontal Plane 25.4 cm (10 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles					
			5		50		95	
L 165								
L 150								
L 135								
L 120								
L 105								
L 90							34.3	(13.5)
L 75							43.7	(17.2)
L 60					41.9	(16.5)	53.3	(21.0)
L 45					49.5	(19.5)	58.9	(23.2)
L 30					53.3	(21.0)	62.7	(24.7)
L 15					55.9	(22.0)	66.5	(26.2)
0								
R 15								
R 30	66.5	(26.2)	68.6	(27.0)	74.2	(29.2)	83.8	(33.0)
R 45	69.1	(27.2)	71.6	(28.2)	77.5	(30.5)	85.6	(33.7)
R 60	71.1	(28.0)	73.7	(29.0)	78.0	(30.7)	85.1	(33.5)
R 75	71.6	(28.2)	74.2	(29.2)	78.0	(30.7)	85.1	(33.5)
R 90	71.6	(28.2)	74.2	(29.2)	78.7	(31.0)	85.1	(33.5)
R 105	70.4	(27.7)	72.9	(28.7)	77.5	(30.5)	83.1	(32.7)
R 120	67.8	(26.7)	70.4	(27.7)	75.4	(29.7)	80.0	(31.5)
R 135			66.5	(26.2)	71.6	(28.2)	78.0	(30.7)
R 150					64.0	(25.2)	72.9	(28.7)
R 165								
180								

Note. Data given in centimeters with inches in parentheses.

Table 7-25. Men's Right-Hand Grasping Reach to a Horizontal Plane 38.1 cm (15 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles					
			5		50		95	
L 165								
L 150								
L 135								
L 120								
L 105								
L 90							44.5	(17.5)
L 75							50.8	(20.0)
L 60					48.8	(19.2)	58.4	(23.0)
L 45			48.3	(19.0)	54.6	(21.5)	65.3	(25.7)
L 30	53.3	(21.0)	55.1	(21.7)	61.0	(24.0)	69.1	(27.2)
L 15	57.2	(22.5)	58.9	(23.2)	66.0	(26.0)	72.9	(28.7)
0	61.5	(24.2)	62.7	(24.7)	72.9	(28.7)	78.7	(31.0)
R 15	66.0	(26.0)	67.3	(26.5)	77.5	(30.5)	86.4	(34.0)
R 30	71.6	(28.2)	72.4	(28.5)	80.0	(31.5)	88.9	(35.0)
R 45	74.9	(29.5)	76.2	(30.0)	83.1	(32.7)	90.2	(35.5)
R 60	76.2	(30.0)	78.7	(31.0)	82.6	(32.5)	88.1	(34.7)
R 75	76.2	(30.0)	80.0	(31.5)	82.6	(32.5)	88.1	(34.7)
R 90	76.7	(30.2)	78.7	(31.0)	82.6	(32.5)	88.1	(34.7)
R 105	76.2	(30.0)	78.0	(30.7)	81.8	(32.2)	87.6	(34.5)
R 120	73.7	(29.0)	74.9	(29.5)	81.3	(32.0)	85.6	(33.7)
R 135					76.2	(30.0)	82.6	(32.5)
R 150							74.9	(29.5)
R 165								
180								

Note. Data given in centimeters with inches in parentheses.

Table 7-26. Men's Right-Hand Grasping Reach to a Horizontal Plane 50.8 cm (20 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles					
			5		50		95	
L 165								
L 150								
L 135								
L 120								
L 105								
L 90					35.6	(14.0)	47.5	(18.7)
L 75					45.7	(18.0)	54.6	(21.5)
L 60	43.2	(17.0)	44.5	(17.5)	52.1	(20.5)	62.2	(24.5)
L 45	46.2	(18.2)	49.5	(19.5)	57.7	(22.7)	67.8	(26.7)
L 30	51.3	(20.2)	54.6	(21.5)	62.7	(24.7)	71.6	(28.2)
L 15	57.2	(22.5)	59.7	(23.5)	67.8	(26.7)	75.4	(29.7)
0	63.5	(25.0)	64.8	(25.5)	72.9	(28.7)	80.5	(31.7)
R 15	69.1	(27.2)	71.1	(28.0)	77.5	(30.5)	86.4	(34.0)
R 30	73.7	(29.0)	76.2	(30.0)	81.3	(32.0)	90.7	(35.7)
R 45	77.5	(30.5)	78.7	(31.0)	85.1	(33.5)	91.9	(36.2)
R 60	80.0	(31.5)	81.3	(32.0)	85.6	(33.7)	91.9	(36.2)
R 75	80.0	(31.5)	81.8	(32.2)	86.4	(34.0)	92.7	(36.5)
R 90	80.5	(31.7)	81.8	(32.2)	86.4	(34.0)	91.4	(36.0)
R 105	80.0	(31.5)	80.5	(31.7)	85.1	(33.5)	90.7	(35.7)
R 120			77.5	(30.5)	83.8	(33.0)	90.2	(35.5)
R 135							87.6	(34.5)
R 150								
R 165								
180								

Note. Data given in centimeters with inches in parentheses.

Table 7-27. Men's Right-Hand Grasping Reach to a Horizontal Plane 63.5 cm (25 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles					
			5		50		95	
L 165								
L 150								
L 135								
L 120								
L 105							45.0	(17.7)
L 90					39.9	(15.7)	51.3	(20.2)
L 75					48.8	(19.2)	56.4	(22.2)
L 60	45.0	(17.7)	46.2	(18.2)	54.6	(21.5)	62.7	(24.7)
L 45	48.8	(19.2)	50.8	(20.0)	58.9	(23.2)	69.1	(27.2)
L 30	54.6	(21.5)	57.2	(22.5)	63.5	(25.0)	72.4	(28.5)
L 15	58.9	(23.2)	61.0	(24.0)	68.6	(27.0)	75.4	(29.7)
0	63.5	(25.0)	66.5	(26.2)	72.4	(28.5)	80.0	(31.5)
R 15	69.1	(27.2)	71.6	(28.2)	76.7	(30.2)	85.1	(33.5)
R 30	74.2	(29.2)	76.7	(30.2)	82.6	(32.5)	89.4	(35.2)
R 45	77.5	(30.5)	78.7	(31.0)	85.1	(33.5)	90.7	(35.7)
R 60	78.7	(31.0)	80.0	(31.5)	85.6	(33.7)	94.0	(37.0)
R 75	80.0	(31.5)	81.3	(32.0)	85.1	(33.5)	92.7	(36.5)
R 90	80.5	(31.7)	81.8	(32.2)	85.6	(33.7)	91.9	(36.2)
R 105	79.2	(31.2)	80.0	(31.5)	85.1	(33.5)	91.4	(36.0)
R 120			77.5	(30.5)	84.3	(33.2)	90.2	(35.5)
R 135							88.9	(35.0)
R 150								
R 165								
180								

Note. Data given in centimeters with inches in parentheses.

Table 7-28. Men's Right-Hand Grasping Reach to a Horizontal Plane 76.2 cm (30 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles 5		50		95	
L 165							47.5	(18.7)
L 150							48.8	(19.2)
L 135							50.8	(20.0)
L 120							47.5	(18.7)
L 105							48.3	(19.0)
L 90					42.4	(16.7)	52.6	(20.7)
L 75					47.5	(18.7)	57.2	(22.5)
L 60	43.2	(17.0)	43.7	(17.2)	52.6	(20.7)	62.2	(24.5)
L 45	46.2	(18.2)	48.3	(19.0)	57.2	(22.5)	67.3	(26.5)
L 30	50.0	(19.7)	54.6	(21.5)	62.2	(24.5)	71.6	(28.2)
L 15	55.9	(22.0)	60.2	(23.7)	67.8	(26.7)	74.9	(29.5)
0	60.2	(23.7)	64.8	(25.5)	72.4	(28.5)	78.7	(31.0)
R 15	66.0	(26.0)	69.1	(27.2)	75.4	(29.7)	83.8	(33.0)
R 30	70.4	(27.7)	73.7	(29.0)	80.0	(31.5)	86.9	(34.2)
R 45	72.9	(28.7)	76.7	(30.2)	81.8	(32.2)	88.1	(34.7)
R 60	76.2	(30.0)	78.7	(31.0)	83.1	(32.7)	90.7	(35.7)
R 75	78.0	(30.7)	79.2	(31.2)	83.8	(33.0)	90.2	(35.5)
R 90	78.7	(31.0)	79.2	(31.2)	84.3	(33.2)	90.7	(35.7)
R 105	78.0	(30.7)	78.7	(31.0)	83.8	(33.0)	89.4	(35.2)
R 120			76.7	(30.2)	82.6	(32.5)	88.1	(34.7)
R 135							87.6	(34.5)
R 150								
R 165							49.5	(19.5)
180							51.3	(20.2)

Note. Data given in centimeters with inches in parentheses.

Table 7-29. Men's Right-Hand Grasping Reach to a Horizontal Plane 88.9 cm (35 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles 5		50		95	
L 165					37.3	(14.7)	53.3	(21.0)
L 150					34.8	(13.7)	50.8	(20.0)
L 135					33.5	(13.2)	48.3	(19.0)
L 120			27.2	(10.7)	33.5	(13.2)	47.5	(18.7)
L 105			31.0	(12.2)	35.6	(14.0)	47.5	(18.7)
L 90	32.3	(12.7)	34.8	(13.7)	39.4	(15.5)	50.8	(20.0)
L 75	36.1	(14.2)	38.1	(15.0)	43.7	(17.2)	53.3	(21.0)
L 60	38.6	(15.2)	40.6	(16.0)	47.5	(18.7)	54.6	(21.5)
L 45	41.1	(16.2)	43.7	(17.2)	52.1	(20.5)	62.7	(24.7)
L 30	45.7	(18.0)	48.8	(19.2)	57.2	(22.5)	66.5	(26.2)
L 15	48.8	(19.2)	53.3	(21.0)	62.7	(24.7)	68.6	(27.0)
0	52.6	(20.7)	56.4	(22.2)	67.3	(26.5)	72.4	(28.5)
R 15	57.7	(22.7)	62.7	(24.7)	70.4	(27.7)	78.7	(31.0)
R 30	62.2	(24.5)	67.8	(26.7)	74.2	(29.2)	83.1	(32.7)
R 45	67.8	(26.7)	71.6	(28.2)	77.5	(30.5)	85.6	(33.7)
R 60	71.1	(28.0)	73.7	(29.0)	78.7	(31.0)	85.6	(33.7)
R 75	72.9	(28.7)	74.9	(29.5)	79.2	(31.2)	86.4	(34.0)
R 90	73.7	(29.0)	75.4	(29.7)	79.2	(31.2)	85.1	(33.5)
R 105	73.7	(29.0)	75.4	(29.7)	80.0	(31.5)	85.1	(33.5)
R 120	72.4	(28.5)	73.7	(29.0)	78.7	(31.0)	85.1	(33.5)
R 135					72.39	(28.5)	85.1	(33.5)
R 150							80.0	(31.5)
R 165							55.1	(21.7)
180					41.9	(16.5)	56.4	(22.2)

Note. Data given in centimeters with inches in parentheses.

Table 7-30. Men's Right-Hand Grasping Reach to a Horizontal Plane 101.6 cm (40 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to			Percentiles					
left or right	Minimum		5		50		95	
L 165					39.4	(15.5)	54.6	(21.5)
L 150					37.3	(14.7)	50.8	(20.0)
L 135					35.6	(14.0)	48.8	(19.2)
L 120			28.4	(11.2)	33.5	(13.2)	47.0	(18.5)
L 105			29.7	(11.7)	33.5	(13.2)	46.2	(18.2)
L 90	30.5	(12.0)	31.0	(12.2)	34.8	(13.7)	46.2	(18.2)
L 75	31.0	(12.2)	31.8	(12.5)	38.1	(15.0)	47.5	(18.7)
L 60	31.8	(12.5)	33.5	(13.2)	41.1	(16.2)	50.8	(20.0)
L 45	33.0	(13.0)	35.6	(14.0)	45.0	(17.7)	54.6	(21.5)
L 30	34.8	(13.7)	39.4	(15.5)	49.5	(19.5)	59.7	(23.5)
L 15	38.6	(15.2)	43.2	(17.0)	53.8	(21.2)	62.2	(24.5)
0	43.2	(17.0)	48.3	(19.0)	58.4	(23.0)	65.3	(25.7)
R 15	47.5	(18.7)	53.3	(21.0)	62.2	(24.5)	72.4	(28.5)
R 30	53.3	(21.0)	57.7	(22.7)	66.5	(26.2)	77.5	(30.5)
R 45	58.9	(23.2)	62.7	(24.7)	70.4	(27.7)	80.0	(31.5)
R 60	61.5	(24.2)	64.8	(25.5)	71.1	(28.0)	79.2	(31.2)
R 75	63.5	(25.0)	66.0	(26.0)	71.1	(28.0)	80.0	(31.5)
R 90	63.5	(25.0)	66.5	(26.2)	71.6	(28.2)	80.0	(31.5)
R 105	65.3	(25.7)	67.8	(26.7)	72.4	(28.5)	80.5	(31.7)
R 120			66.5	(26.2)	72.9	(28.7)	80.0	(31.5)
R 135					68.6	(27.0)	78.7	(31.0)
R 150							74.2	(29.2)
R 165					42.4	(16.7)	60.2	(23.7)
180					45.0	(17.7)	59.7	(23.5)

Note. Data given in centimeters with inches in parentheses.

Table 7-31. Men's Right-Hand Grasping Reach to a Horizontal Plane 114.3 cm (45 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum		Percentiles					
			5		50		95	
L 165			26.7	(10.5)	35.6	(14.0)	50.8	(20.0)
L 150	21.6	(8.5)	22.1	(8.7)	31.0	(12.2)	46.2	(18.2)
L 135	19.1	(7.5)	19.6	(7.7)	27.9	(11.0)	42.4	(16.7)
L 120	17.8	(7.0)	19.1	(7.5)	26.7	(10.5)	39.4	(15.5)
L 105	17.0	(6.7)	18.3	(7.2)	25.9	(10.2)	38.1	(15.0)
L 90	17.0	(6.7)	18.3	(7.2)	26.7	(10.5)	38.1	(15.0)
L 75	17.0	(6.7)	19.1	(7.5)	27.9	(11.0)	38.6	(15.2)
L 60	17.8	(7.0)	19.6	(7.7)	30.5	(12.0)	41.1	(16.2)
L 45	19.1	(7.5)	21.6	(8.5)	34.3	(13.5)	46.2	(18.2)
L 30	21.6	(8.5)	24.1	(9.5)	38.1	(15.0)	50.0	(19.7)
L 15	25.4	(10.0)	27.9	(11.0)	41.9	(16.5)	53.8	(21.2)
0	28.4	(11.2)	32.3	(12.7)	46.2	(18.2)	57.7	(22.7)
R 15	33.0	(13.0)	39.4	(15.5)	50.8	(20.0)	62.7	(24.7)
R 30	37.3	(14.7)	44.5	(17.5)	55.9	(22.0)	66.5	(26.2)
R 45	43.7	(17.2)	48.3	(19.0)	59.7	(23.5)	68.6	(27.0)
R 60	48.8	(19.2)	52.1	(20.5)	61.0	(24.0)	69.1	(27.2)
R 75	49.5	(19.5)	52.1	(20.5)	61.0	(24.0)	69.9	(27.5)
R 90	50.0	(19.7)	53.3	(21.0)	61.5	(24.2)	70.4	(27.7)
R 105	51.3	(20.2)	54.6	(21.5)	62.2	(24.5)	71.1	(28.0)
R 120	50.0	(19.7)	53.8	(21.2)	62.2	(24.5)	70.4	(27.7)
R 135	47.5	(18.7)	50.8	(20.0)	58.9	(23.2)	70.4	(27.7)
R 150			39.4	(15.5)	52.6	(20.7)	66.0	(26.0)
R 165			37.3	(14.7)	45.7	(18.0)	57.7	(22.7)
180			32.3	(12.7)	41.9	(16.5)	54.6	(21.5)

Note. Data given in centimeters with inches in parentheses.

Table 7-32. Women's Right-Hand Grasping Reach to a Horizontal Plane through the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles					
		5		50		95	
L 165							
L 150							
L 135							
L 120							
L 105							
L 90							
L 75							
L 60							
L 45							
L 30							
L 15							
0							
R 15						55.9	(22.0)
R 30				41.1	(16.2)	55.1	(21.7)
R 45		35.6	(14.0)	44.5	(17.5)	56.4	(22.2)
R 60		38.6	(15.2)	47.5	(18.7)	58.4	(23.0)
R 75		41.1	(16.2)	48.3	(19.0)	60.2	(23.7)
R 90		42.4	(16.7)	49.5	(19.5)	60.2	(23.7)
R 105		40.6	(16.0)	48.3	(19.0)	58.4	(23.0)
R 120		38.6	(15.2)	46.2	(18.2)	55.9	(22.0)
R 135		33.0	(13.0)	41.9	(16.5)	52.1	(20.5)
R 150				33.0	(13.0)	47.5	(18.7)
R 165						39.9	(15.7)
180							

Note. Data given in centimeters with inches in parentheses.

Table 7-33. Women's Right-Hand Grasping Reach to a Horizontal Plane 15.2 cm (6 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles 5	 50	 95
L 165				
L 150				
L 135				
L 120				
L 105				26.7 (10.5)
L 90				29.2 (11.5)
L 75				36.8 (14.5)
L 60				40.6 (16.0)
L 45				45.7 (18.0)
L 30				50.8 (20.0)
L 15				
0				
R 15		50.8 (20.0)	57.2 (22.5)	67.3 (26.5)
R 30		53.3 (21.0)	58.4 (23.0)	69.9 (27.5)
R 45		54.6 (21.5)	60.2 (23.7)	71.1 (28.0)
R 60		58.9 (23.2)	63.5 (25.0)	71.1 (28.0)
R 75		60.2 (23.7)	63.5 (25.0)	72.4 (28.5)
R 90		60.2 (23.7)	64.0 (25.2)	72.4 (28.5)
R 105		58.9 (23.2)	63.5 (25.0)	70.4 (27.7)
R 120		55.9 (22.0)	61.0 (24.0)	66.5 (26.2)
R 135		52.6 (20.7)	58.4 (23.0)	64.8 (25.5)
R 150			50.8 (20.0)	61.0 (24.0)
R 165			41.1 (16.2)	53.3 (21.0)
180				

Note. Data given in centimeters with inches in parentheses.

Table 7-34. Women's Right-Hand Grasping Reach to a Horizontal Plane 30.5 cm (12 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles					
		5		50		95	
L 165							
L 150							
L 135							
L 120						32.3	(12.7)
L 105						35.6	(14.0)
L 90				27.9	(11.0)	39.4	(15.5)
L 75				33.0	(13.0)	44.5	(17.5)
L 60		31.0	(12.2)	38.1	(15.0)	50.8	(20.0)
L 45		36.8	(14.5)	45.0	(17.7)	54.6	(21.5)
L 30		41.9	(16.5)	50.8	(20.0)	57.7	(22.7)
L 15		48.3	(19.0)	55.1	(21.7)	62.2	(24.5)
0		54.6	(21.5)	59.7	(23.5)	66.0	(26.0)
R 15		58.4	(23.0)	63.5	(25.0)	71.1	(28.0)
R 30		61.0	(24.0)	66.0	(26.0)	74.2	(29.2)
R 45		64.8	(25.5)	69.1	(27.2)	76.2	(30.0)
R 60		67.3	(26.5)	71.6	(28.2)	78.0	(30.7)
R 75		67.8	(26.7)	71.6	(28.2)	78.7	(31.0)
R 90		69.1	(27.2)	72.4	(28.5)	78.7	(31.0)
R 105		67.3	(26.5)	72.4	(28.5)	78.7	(31.0)
R 120				69.9	(27.5)	74.9	(29.5)
135				64.8	(25.5)	71.6	(28.2)
R 150				48.3	(19.0)	63.5	(25.0)
R 165						57.2	(22.5)
180							

Note. Data given in centimeters with inches in parentheses.

Table 7-35. Women's Right-Hand Grasping Reach to a Horizontal Plane 45 cm (18 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles					
		5		50		95	
L 165							
L 150							
L 135							
L 120						35.6	(14.0)
L 105				27.9	(11.0)	39.4	(15.5)
L 90		26.7	(10.5)	33.0	(13.0)	43.7	(17.2)
L 75		29.7	(11.7)	38.1	(15.0)	50.0	(19.7)
L 60		35.6	(14.0)	45.0	(17.7)	53.3	(21.0)
L 45		42.4	(16.7)	50.0	(19.7)	58.4	(23.0)
L 30		47.5	(18.7)	54.6	(21.5)	61.5	(24.2)
L 15		50.8	(20.0)	58.4	(23.0)	66.0	(26.0)
0		57.2	(22.5)	62.7	(24.7)	69.9	(27.5)
R 15		61.5	(24.2)	66.5	(26.2)	74.9	(29.5)
R 30		64.8	(25.5)	69.9	(27.5)	76.7	(30.2)
R 45		67.8	(26.7)	72.9	(28.7)	78.7	(31.0)
R 60		70.4	(27.7)	74.9	(29.5)	81.3	(32.0)
R 75		70.4	(27.7)	75.4	(29.7)	81.3	(32.0)
R 90		71.1	(28.0)	76.2	(30.0)	80.5	(31.7)
R 105		69.9	(27.5)	76.7	(30.2)	81.8	(32.2)
R 120				72.9	(28.7)	78.7	(31.0)
R 135						71.6	(28.2)
R 150						38.1	(15.0)
R 165							
180							

Note. Data given in centimeters with inches in parentheses.

Table 7-36. Women's Right-Hand Grasping Reach to a Horizontal Plane 61 cm (24 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to		Percentiles					
left or right	Minimum	5		50		95	
L 165				22.9	(9.0)	38.1	(15.0)
L 150				22.9	(9.0)	40.6	(16.0)
L 135				27.2	(10.7)	35.6	(14.0)
L 120				25.4	(10.0)	42.4	(16.7)
L 105		20.3	(8.0)	31.0	(12.2)	48.3	(19.0)
L 90		25.4	(10.0)	37.3	(14.7)	45.0	(17.7)
L 75		29.2	(11.5)	40.6	(16.0)	53.3	(21.0)
L 60		36.1	(14.2)	47.0	(18.5)	54.6	(21.5)
L 45		43.2	(17.0)	50.8	(20.0)	59.7	(23.5)
L 30		48.3	(19.0)	55.1	(21.7)	62.7	(24.7)
L 15		52.1	(20.5)	58.4	(23.0)	66.0	(26.0)
0		55.9	(22.0)	63.5	(25.0)	71.1	(28.0)
R 15		59.7	(23.5)	66.5	(26.2)	74.9	(29.5)
R 30		63.5	(25.0)	69.9	(27.5)	76.7	(30.2)
R 45		66.5	(26.2)	72.4	(28.5)	78.7	(31.0)
R 60		67.8	(26.7)	74.2	(29.2)	81.3	(32.0)
R 75		68.6	(27.0)	76.2	(30.0)	81.3	(32.0)
R 90		69.9	(27.5)	77.5	(30.5)	81.3	(32.0)
R 105		69.1	(27.2)	76.7	(30.2)	81.8	(32.2)
R 120		33.0	(13.0)	72.4	(28.5)	78.7	(31.0)
R 135		27.9	(11.0)	35.6	(14.0)	68.6	(27.0)
R 150		22.9	(9.0)	30.5	(12.0)	55.9	(22.0)
R 165		20.8	(8.2)	28.4	(11.2)	45.7	(18.0)
180				27.9	(11.0)	40.6	(16.0)

Note. Data given in centimeters with inches in parentheses.

Table 7-37. Women's Right-Hand Grasping Reach to a Horizontal Plane 76.2 cm (30 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles					
		5		50		95	
L 165		18.3	(7.2)	31.8	(12.5)	48.8	(19.2)
L 150		15.7	(6.2)	30.5	(12.0)	41.9	(16.5)
L 135		17.0	(6.7)	22.1	(8.7)	38.6	(15.2)
L 120		17.8	(7.0)	27.2	(10.7)	43.2	(17.0)
L 105		16.5	(6.5)	30.5	(12.0)	45.7	(18.0)
L 90		22.1	(8.7)	33.0	(13.0)	43.7	(17.2)
L 75		25.4	(10.0)	39.4	(15.5)	50.8	(20.0)
L 60		33.0	(13.0)	44.5	(17.5)	53.3	(21.0)
L 45		38.1	(15.0)	48.3	(19.0)	55.9	(22.0)
L 30		43.2	(17.0)	52.1	(20.5)	61.5	(24.2)
L 15		46.2	(18.2)	55.9	(22.0)	64.0	(25.2)
0		50.8	(20.0)	58.4	(23.0)	68.6	(27.0)
R 15		54.6	(21.5)	62.2	(24.5)	71.6	(28.2)
R 30		57.2	(22.5)	65.3	(25.7)	73.7	(29.0)
R 45		58.9	(23.2)	69.9	(27.5)	75.4	(29.7)
R 60		62.2	(24.5)	70.4	(27.7)	77.5	(30.5)
R 75		64.0	(25.2)	72.4	(28.5)	76.7	(30.2)
L 90		65.3	(25.7)	72.9	(28.7)	78.7	(31.0)
R 105		66.0	(26.0)	73.7	(29.0)	78.7	(31.0)
R 120		41.1	(16.2)	66.5	(26.2)	74.9	(29.5)
R 135		32.3	(12.7)	49.5	(19.5)	69.9	(27.5)
R 150		27.9	(11.0)	41.1	(16.2)	59.7	(23.5)
R 165		26.7	(10.5)	39.4	(15.5)	55.9	(22.0)
180		24.1	(9.5)	38.1	(15.0)	50.8	(20.0)

Note. Data given in centimeters with inches in parentheses.

Table 7-38. Women's Right-Hand Grasping Reach to a Horizontal Plane 91.4 cm (36 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles					
		5		50		95	
L 165		22.9	(9.0)	33.0	(13.0)	49.5	(19.5)
L 150		20.3	(8.0)	29.2	(11.5)	45.0	(17.7)
L 135		18.3	(7.2)	25.9	(10.2)	40.6	(16.0)
L 120		18.3	(7.2)	25.4	(10.0)	39.4	(15.5)
L 105		18.3	(7.2)	26.7	(10.5)	38.6	(15.2)
L 90		19.6	(7.7)	29.2	(11.5)	40.6	(16.0)
L 75		20.8	(8.2)	33.0	(13.0)	43.7	(17.2)
L 60		25.4	(10.0)	36.1	(14.2)	45.7	(18.0)
L 45		29.2	(11.5)	39.4	(15.5)	49.5	(19.5)
L 30		33.5	(13.2)	43.7	(17.2)	54.6	(21.5)
L 15		36.1	(14.2)	48.3	(19.0)	57.7	(22.7)
0		41.1	(16.2)	52.1	(20.5)	61.0	(24.0)
R 15		44.5	(17.5)	54.6	(21.5)	62.7	(24.7)
R 30		47.0	(18.5)	57.2	(22.5)	66.0	(26.0)
R 45		48.8	(19.2)	61.0	(24.0)	68.6	(27.0)
R 60		52.6	(20.7)	63.5	(25.0)	70.4	(27.7)
R 75		53.3	(21.0)	64.8	(25.5)	71.1	(28.0)
R 90		56.4	(22.2)	66.5	(26.2)	72.9	(28.7)
R 105		53.8	(21.2)	66.5	(26.2)	72.9	(28.7)
R 120		46.2	(18.2)	63.5	(25.0)	70.4	(27.7)
R 135		31.8	(12.5)	48.3	(19.0)	65.3	(25.7)
R 150		25.4	(10.0)	43.7	(17.2)	59.7	(23.5)
R 165		25.9	(10.2)	40.6	(16.0)	55.9	(22.0)
180		24.1	(9.5)	38.6	(15.2)	53.8	(21.2)

Note. Data given in centimeters with inches in parentheses.

Table 7-39. Women's Right-Hand Grasping Reach to a Horizontal Plane 106.7 cm (42 in.) above the Seat Reference Point (From Webb Associates, 1978.)

Angle to left or right	Minimum	Percentiles					
		5		50		95	
L 165		12.7	(5.0)	25.9	(10.2)	43.2	(17.0)
L 150		10.7	(4.2)	22.9	(9.0)	38.1	(15.0)
L 135		9.4	(3.7)	21.6	(8.5)	34.8	(13.7)
L 120		8.9	(3.5)	20.3	(8.0)	33.0	(13.0)
L 105		8.1	(3.2)	20.3	(8.0)	31.8	(12.5)
L 90		8.9	(3.5)	20.3	(8.0)	33.0	(13.0)
L 75		9.4	(3.7)	22.1	(8.7)	36.8	(14.5)
L 60		10.2	(4.0)	24.1	(9.5)	41.1	(16.2)
L 45		11.9	(4.7)	26.7	(10.5)	40.6	(16.0)
L 30		14.0	(5.5)	29.2	(11.5)	43.2	(17.0)
L 15		16.5	(6.5)	31.8	(12.5)	45.0	(17.7)
0		19.1	(7.5)	35.6	(14.0)	47.0	(18.5)
R 15		22.9	(9.0)	40.6	(16.0)	48.3	(19.0)
R 30		25.4	(10.0)	43.2	(17.0)	52.1	(20.5)
R 45		28.4	(11.2)	44.5	(17.5)	55.9	(22.0)
R 60		30.5	(12.0)	48.3	(19.0)	57.2	(22.5)
R 75		33.0	(13.0)	50.8	(20.0)	59.7	(23.5)
R 90		35.6	(14.0)	50.8	(20.0)	61.0	(24.0)
R 105		35.6	(14.0)	52.1	(20.5)	61.0	(24.0)
R 120		30.5	(12.0)	47.0	(18.5)	59.7	(23.5)
R 135		23.4	(9.2)	39.4	(15.5)	53.8	(21.2)
R 150		19.1	(7.5)	35.6	(14.0)	50.0	(19.7)
R 165		16.5	(6.5)	31.0	(12.2)	48.3	(19.0)
180		14.0	(5.5)	27.9	(11.0)	47.5	(18.7)

Note. Data given in centimeters with inches in parentheses.

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APPENDIX A: DEFINITIONS AND MEASUREMENT UNITS

Visual Angle

Visual angle is the angle subtended at the observer's eye by the viewed object. It is usually expressed in minutes of arc and is computed by the equation:

$$\text{Visual angle (minutes of arc)} = \frac{(57.3)(60)L}{D}$$

where L is the size of the object measured perpendicular to the observer's line of sight, and D is the distance from the observer's eye to the object. The values 57.3 and 60 are constants for angles less than 600 minutes.

To determine target size (L) for a known visual angle and distance (D), the terms of the equation are transposed as follows:

$$L = \frac{(\text{visual angle})\ D}{(57.3)(60)}$$

Illumination

Illumination is a measure of the amount of light falling on a surface or object, and is alternatively called illuminance. A common unit of illuminance is the footcandle (fc), which is the density of light falling on the inner surface of a sphere of 1 foot radius when a point of light with an intensity of one candela (cd) is placed at the center of the sphere. The metric unit of illuminance is a lux (lx), which is the illumination on a spherical surface 1 meter square at a radius of 1 meter. The conversion factors between units are: 1 fc = 10.76 lx; 1 lx = 0.0929 fc.

Illuminance is a function of the distance from the light source in accordance with the inverse square law, and it is determined as follows:

$$\text{Illuminance (lx)} = \frac{\text{intensity of light source (cd)}}{\text{distance (m)}^2}$$

Luminance

Luminance is a measure of the amount of light reflected from a surface. It is often referred to as brightness; but brightness is the resulting sensory experience that can be influenced by contrast, adaptation, and other factors in addition to the physical energy of the light. Distance is not a factor in the determination of luminance; it is the same whether it is measured, say, 2 or 4 feet away. The commonly used unit of luminance is the footlambert (fL), which is equivalent to $1/\pi$ cd/ft^2. Other units of luminance are the lambert ($1/\pi$ cd/cm^2) and the millilambert (mL). The millilambert is 1/1000 lambert and nearly equal to a footlambert (1.076 fL = 1 mL).

The nit is the metric unit of luminance and is equivalent to $1/\pi$ $cd/meter^2$. The conversion between units of luminance is accomplished as follows:

1 fL = 3.4264 nits
1 nit = 0.292 fL

Reflectance

Reflectance is a measure of the relationship between the illumination reaching a surface and the resulting luminance. It is defined by the following formula:

$$\text{Reflectance (\%)} = 100 \times \frac{\text{luminance}}{\text{illuminance}}$$

Required Illumination

The illuminance required for a task can be computed from the following formula:

$$\text{Required illuminance} = \frac{\text{required luminance}}{\text{\% reflectance}}$$

Luminance (Brightness) Contrast

Luminance contrast is a measure of the difference between the luminance of a target and the luminance of the background. It is computed by the following formula:

$$\text{Luminance contrast (\%)} = 100 \times \frac{Lb - Ld}{Lb}$$

where Lb is the luminance of the brighter area, and Ld is the luminance of the darker area.

APPENDIX B: ANNOTATED BIBLIOGRAPHY

IOS Design Reports

Booker, J.L., & Golovcsenko, I.V. (1971). Instructor console instrument simulation, Interim report (NAVTRADEVCEN-IH-195, AD-731 739). Orlando, FL: Computer Laboratory, Naval Training Device Center.

Abstract. The object of the task is to investigate the use of computer-generated display devices in training device instructor console applications. The first phase in accomplishing this objective is to demonstrate the ability to provide all control and monitoring functions presently available from conventional instructor consoles. Typical functions to be provided are the insertion of various normal and abnormal problem conditions, the initiation of various test aid functions, control over the modes of operation, and a duplicate set of instruments and indicators from the simulated vehicle trainee station.

The TRADEC Sigma 7 simulation of an F4E aircraft represents a contemporary example of an aviation training device digital simulation. The F4E instructor console exemplifies most of the types of instrumentation encountered in present-day aircraft simulator instructor stations. Availability of the TRADEC display system interfaced to the Sigma 7 provided an excellent opportunity to accomplish a complete simulation of the TRADEC instructor console on the display system.

At the time of this interim report, 17 of the total of 19 flight instruments have been interfaced to the flight program and successfully simulated on the TRADEC display system. A display system executive program was developed to provide for interactive control of display formats. It provides pushbutton selection of individual and grouped instruments.

It is planned that the control functions represented by 64 back-lighted pushbuttons on the conventional F4E instructor console will be simulated through a light-pen selectable menu of options around the periphery of the display screen. A capability to position instruments on the display scope using the light-pen is being incorporated at the time of this writing. This capability will provide for regrouping and reconfiguration of the display format as an interactive function.

CAE Electronics, Ltd. (1981). Instructor-simulator interface design (AFHRL-TR-80-48, AD-A098 849). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Abstract. Most flight simulators in service today are operated from instructor stations where design requirements have been established by subjective opinion, past experience, and space and equipment constraints. In contrast, crew stations of simulators, being replicas of aircraft crew compartments, reflect painstaking, systematic efforts in human engineering and pilot evaluation. To improve the overall quality of simulation, then, efforts should be directed at improving the efficiency and operability of instructor facilities. The objective of this study is to develop a method of evaluating the degree to which an instructor/operation station (IOS) design bridges the gap between human characteristics and machine requirements. An objective evaluation methodology should assist the designer in assessing a tentative IOS design by identifying devices and functions responsible for poor system performance. A secondary objective of the study was to apply this tool to evaluate the effectiveness of various interface layouts and devices. The primary purpose of this report is to describe the development, test, and application of a computer-assisted evaluation technique which resulted from this study.

Caro, P.W., Pohlmann, L.D., & Isley, R.N. (1979). *Development of simulator instructional feature design guide* (TR-79-12). Pensacola, FL: Seville Research Corporation.

Abstract. A project to develop guides for the design of simulator instructional features is described. Twelve instructional features, e.g., record/playback, automatic demonstration, and freeze, appropriate to a fighter/attack-type aircraft simulator were identified. Information concerning each feature was obtained through observation of simulator instructional activities and review of training requirements and practices. The types of pilots likely to undergo training in a fighter/attack aircraft were examined to identify learner-related simulator design requirements. A guide format was developed that would permit organization of pertinent information in a manner useful to simulator design personnel. The guides were reviewed by personnel involved in the development of both aircraft and non-aircraft simulators and were judged useful as a mechanism for clarifying design requirements, communicating between training and simulator design personnel, highlighting design shortfalls, and clarifying simulator testing requirements.

Charles, J.P. (1984). *Design guidelines for trainer instructor/operator stations* (NAVTRAEQUIPCEN-83-C-0087-1). Orlando, FL: Naval Training Equipment Center.

Summary. It became clear following a series of reviews of trainer operating consoles that a variety of operability and related training effectiveness problems exist in many operational trainers. It appeared that similar problems will occur in future trainers unless the procedures and methods for the design of trainer consoles are revised and implemented. Therefore, a project was undertaken to develop a new set of guidelines for the design and development of trainer instructor/operator stations.

The earlier reviews had pointed out a basic overall lack of application of both systems methodology and human factors engineering criteria to the design of training device instructor/operator stations. Both the methodology and the criteria exist. Therefore, the general approach employed for the preparation of the guide was to develop detailed procedures for console definition, development and support utilizing that methodology. Since the approach (the systems engineering approach) should also be used in trainer design and development, a common design approach could be utilized overall for the trainer development project.

The guidelines contained in this report are divided into three sections reflecting the three basic phases of training device procurement, namely:

Precontract Phase - directed to the analysis of the requirement and development of the procurement specifications,

Acquisition Phase - directed to the design and development of the trainer and its test and acceptance,

Support Phase - directed to support of the trainer including update and modification during its operational life.

The guidelines are life cycle procedure oriented and rely on the utilization of existing design criteria. They are considered to be adequate and have proven effective over the years when applied within the systems engineering approach.

Among the major problems which surfaced in the reviews of trainer consoles was the lack of consideration of instructional requirements and user characteristics in the design. Thus, the guidelines are directed more to the effort required in monitoring and evaluating products of the design process and ensuring that the steps are completed, rather than with specifying specific design solutions. The latter approach, which must necessarily be identified and associated with a particular state of technology, is rapidly outdated as new technology is developed. Finally, solutions without a problem statement rarely succeed in meeting an operational requirement.

Charles, J.P. (1983). Device 2E6 (ACMS) air combat maneuvering simulator instructor console review (NAVTRAEQUIPCEN-82-M-0767-1). Orlando, FL: Naval Training Equipment Center.

Summary. Two earlier surveys of the Instructor Operator Stations (IOSs) of weapon system trainers (WSTs) conducted by the Naval Training Equipment Center, following reports of problems, revealed a wide variety of design problems. The problems impacted on trainer effectiveness, especially in terms of operability and manning requirements. The surveys verified that significant improvements could and should be made to the IOSs and that changes to the design and procurement process should be implemented. The majority of the problems were considered to stem from the lack of adequate training front-end analysis and from the lack of application of existing human engineering criteria and design data.

This report covers a survey of the IOS of a part-mission trainer, Training Device 2E6, an Air Combat Maneuvering Simulator. The device is significantly different from the WSTs surveyed previously (Device 2F119 and Device 2F112) in terms of the training objectives and in the characteristics of the trainer. The training objectives are concerned exclusively with the visual attack phase of air-to-air combat. Thus, the environment and vehicle simulation requirements are limited and the training events consist of multiple, relatively short-duration "flights."

Training Device 2E6 consists of two domes inside which is projected the simulated visual world and which house the training mockups. Two IOSs are provided so that the two training mockups can be operated as independent trainers. The two trainers can also be "tied" together and operated as a single training device.

The survey of the IOSs included reviewing technical documentation for the device, observing training operations and interviewing instructors, mission operators and technical personnel supporting the trainer. In addition, operating procedures were analyzed. The goal was to identify console design deficiencies and develop feasible solutions, for both short and long term.

A wide variety of problems were found, ranging from basic human engineering defects to utilization and related instructor manning and training problems. Some console problems were created when professional operators were employed to support the instructors in the operation of the device. While solving instructor training problems and providing effective standard operation of the device, serious problems were created since the console was not designed for such manning. As a result, for example, the squadron instructor's station provides very limited control over training features and training events.

Among the conclusions reached was that significant improvements could and should be made to the IOS to enhance training and increase the effectiveness of the instructor as well as of the mission operator. While the device provides some new features which support training, such as a debrief facility and a computer-based instructor training module, the implementation limits their effectiveness. The major problems found include the following:

a. The instructor station displays and controls are inadequate for the instructor to effectively monitor aircrew performance and manage the training event. The required controls and displays are centralized at the Mission Operator station.

b. Insufficient flight and system information is available for the instructor pilot to "fly" the manual target/aircraft. In addition, the task conflicts with the basic instructor function of monitoring student performance and controlling the training event.

c. The CRT display pages do not provide sufficient information for the initialization and control of the training events without extensive paging and mode changes.

d. A wide variety of control and display design problems exist which, although individually minor, combine to affect training operability and trainer capability utilization.

e. The arrangement of the consoles in the training spaces is not optimum.

f. Basic operating procedures such as initialization, debrief implementation and demonstration development are complex and error producing.

g. As found in the other surveys, user documentation for the IOS is limited and not designed for the user or for the functions which must be performed.

A series of recommendations were made to enhance the IOSs. Primary among these was that a display and control analysis be completed before any changes are made to ensure that the instructor and military requirements are well defined and reflect the altered tasks. The detailed recommendations included:

a. Redesign the instructor's station to provide the required controls and displays for monitoring aircrew performance and for managing the training.

b. Reorient the consoles to provide some isolation of the stations from the traffic and congestion in the area.

c. Implement a performance measurement system to provide the instructor objective data to aid in the evaluation of aircrew performance.

d. Simplify the basic operating procedures such as event initialization, debriefing implementation and demonstration development.

Charles, J.P. (1983). Device 2F112 (F-14A WST) instructor console review (NAVTRAEQUIPCEN-81-M-1121-1). Orlando, FL: Naval Training Equipment Center.

Summary. Following reports of operating problems with some of the newer airborne weapon system trainers (WSTs), the Human Factors Laboratory of the Naval Training Equipment Center undertook a critical review of the instructor operator stations of selected trainers. The initial review was of the EA-6B WST (Device 2F119) and was documented in technical report NAVTRAEQUIPCEN 81-M-1083-1. The results verified that significant problems did exist and constrained training effectiveness.

This report covers a review of the WST for the F-14A aircraft, Device 2F112. The device differs from the 2F119 in simulation features, operating philosophy and relationship to other training devices utilized in the training program.

The WST located at the Naval Air Station, Miramar was used for the review. Problems and operations were discussed with personnel at the Fighter Airborne Early Warning Wing Pacific, the Fleet Readiness Squadron (VF-124), fleet squadrons, the Navy Fighter Weapons School, and the Fleet Aviation Specialized Operational Training Group Detachment, all located at the Naval Air Station Miramar. Training operations were observed, documentation was reviewed and analyses of the instructor operating console were conducted. The goal was to identify console design deficiencies and feasible solutions. In addition, the identification of "design guides" which would help preclude similar problems from occurring in the future was undertaken.

A wide variety of problems ranging from basic human engineering defects to utilization and related instructor manning and training problems were found. The employment of professional Mission Operators to operate the trainer, while solving the basic simulator operating problems, has created a new set of problems.

Among the conclusions reached was that while the trainer potentially offers a wide variety of training capabilities, console design deficiencies severely limit its use. These problems include:

a. The instructor stations are too complex for operation by an instructor without extensive training. Displays required for monitoring and evaluating aircrew performance are difficult to access and compete for display space with data needed for control functions. No changes were made to the controls and displays or station design when the Mission Operator concept was implemented. Thus, while the trainer can now be brought "on line" by the Mission Operators, the instructors are still unable to effectively utilize the available displays and related controls to access student data and monitor performance.

b. The Operation Station is inadequate to support the Mission Operator functions. This results in the Mission Operator utilizing instructor station displays and controls, which interferes with instructor functions.

c. The instructor console operability problems result from a general lack of application of existing human engineering and aviation design standards and specifications and accepted aviation aircrew station design practices. Serious layout and arrangement problems, confusing labeling, inconsistent color coding, and poor control mechanization were among the deficiencies found.

d. The device, as designed and implemented, is primarily usable only in the preprogrammed mode since the instructor "interface" was not designed to support training operations or to be operated by a "novice" or relatively naive operator. The utilization is further constrained by the fact that the console is simulation parameter, not training function, oriented.

The recommendations which followed included:

a. A detailed analysis of user requirements and characteristics should be undertaken prior to modifying the instructor console and trainer interfaces.

b. The operator station should be redesigned to meet Mission Operator display and control requirements.

c. The instructor station displays and controls should be redesigned so as to be usable by weapon system instructors for training, with minimal instruction in operation of the device.

d. Trainer software should be modified to permit effective use of trainer modes other than the preprogrammed or "formulated" mode of operation.

e. Trainer operating software should be redesigned to provide support to additional training functions such as brief and debrief.

f. Communications simulation capabilities should be incorporated to reduce instructor-student ratios, especially for the air battle or war-at-sea training events.

g. Performance measurement and mission effectiveness models should be designed and implemented to aid in crew and unit proficiency and readiness assessment.

Charles, J.P. (1982). Device 2F119 (EA-6B WST) instructor console review (NAVTRAEQUIPCEN-81-M-1083-1). Orlando, FL: Naval Training Equipment Center.

Summary. Reports of operating problems with some of the newer airborne weapons systems trainers led the Naval Training Equipment Center (NAVTRAEQUIPCEN) to conduct a review of the instructor console and operational utilization of Device 2F119, the EA-6B Weapon System Trainer. The review included a survey of current training operations, interviews with instructors and training managers, analysis of the console design, and a review of related documentation. The goal was to identify any console design deficiencies and develop feasible solutions. In addition, identification of any "design guides" to preclude similar problems in the future was undertaken.

Visits to Naval Air Station Whidbey Island were made. Problems and operations were discussed with personnel at the Medium Attack Tactical Electronic Warfare Wing Pacific (MATVAQWINGPAC), the Fleet Readiness Squadron (VAQ) 129, the NAVTRAEQUIPCEN Field Engineering Office and at the Fleet Aviation Specialized Operational Training Group Pacific Fleet Detachment NAS Whidbey Island. A sampling of training events involving both the Fleet Readiness Squadron and Fleet

Squadrons were observed and discussed with instructors and operator personnel. Related documentation was reviewed including syllabus guides, scenarios and trainer documentation.

A wide variety of console problems was found, ranging from basic human engineering defects to utilization and related instructor manning and training problems. While many of the design deficiencies were minor in nature, the overall result is such as to seriously impact the device's training effectiveness and costs.

Among the conclusions reached were that while the device is a very sophisticated simulator:

1) Fleet squadron personnel will be unable to operate it except for basic procedures training and similar events unless instructor-operator support is provided.

2) The trainer lacks many basic training functions, which severely limit its effectiveness and usefulness.

3) Many display and control changes are required to achieve the required operability.

4) Changes to trainer procurement and specifications are required to preclude recurrence of similar problems.

The recommendations which followed include:

1) Professional instructor-operators should be hired to support mission training and training event programming.

2) The trainer operating software should be modified to permit simultaneous training operations including mission training, debriefing-replay and hard copy output. In addition, simultaneous use of the flight mode and the tactics mode should be available.

3) Addition of part-task trainers, especially for cockpit procedures and radar/navigation, should be implemented to provide more device time for mission training, which can be expected to increase.

4) Performance and mission effectiveness models should be added to the trainer to aid in individual and crew performance and readiness evaluation. Such models and techniques are state-of-the-art.

5) Display and control deficiencies must be corrected. However, because of the interactive nature of the problems, the feasible solutions, the instructor-operator capabilities, the training scenario and the training objectives, a change requirements analysis and tradeoff should be conducted to ensure that enhancements are made rather than problems compounded.

Charles, J.P. (1977). Instructor pilot's role in simulation training (Phase II) (NAVTRAEQUIPCEN-76-C-0034-1). Orlando, FL: Naval Training Equipment Center.

Summary. The first phase of the study of the Navy Instructor Pilots' Role in the use of flight simulators in fleet pilot training was concerned primarily with reviewing current training operations and training simulators. The report revealed that significant changes have occurred in recent years in terms of instructor personnel and equipment. Most important was the conclusion that simulator instructor consoles are not designed for training implementation and that the instructor pilot (IP) is neither trained in simulator utilization or in "how to instruct." The problems were further compounded by the lack of well-defined simulator training syllabi and supporting documentation.

The second phase of the study has involved the development and detailed analysis of the IP functions in simulator pilot training. In addition, the interaction of the Navy Flight Officer Instructor was analyzed.

A total of 10 functions involving 35 sub-functions was structured. A conceptual console of nine modules which could support these functions was outlined. The interaction and relationship of the Navy Flight Officer (NFO) instructor and the IP were explored for those weapon systems in which an NFO is part of the aircrew.

While the conceptual console module appears to be technically feasible, some laboratory demonstrations and field testing should be conducted before the detailed specification is written.

Charles, J.P., Willard, G., & Healey, G. (1976). Instructor pilot's role in simulator training (NAVTRAEQUIPCEN-75-C-0093-1, AD-A023 546). Orlando, FL: Naval Training Equipment Center.

Summary. The role of the Navy Instructor Pilot (IP) in the use of flight simulators in fleet pilot training is undergoing significant changes as a function of both advances in technology and increased utilization. The utilization can be expected to further increase as simulation training is substituted for flight training. Definition of the role and functions of the IP is essential to instructor console design. This study was directed to defining the role of the IP in current training operations and in advanced trainers under development.

Readiness Training Squadrons and Fleet Aviation Specialized Operational Training Group (FASOTRAGRU) Detachments for all major weapons systems were visited and data on the IP's role, the technician/operator's role and simulation utilization in the training syllabus were collected.

Analysis of the data indicates that the IP's role varies with the system, primarily in terms of crew size and pilot tasks. In general, the details of the IP role cannot be finalized until the role of the Naval Flight Officer Instructor (NFOI) is defined since the NFOI and IP interact extensively in most training systems.

The study also revealed the lack of training for the IP in both simulator operation and utilization and in "how to instruct." As a result, simulator training is not well employed, standardized, or in general appreciated by IPs.

The role of the technician/operator was also reviewed. Major changes to their role in simulation training operations have occurred and other changes will occur as the roles of the IP and NFOI are established.

Instructor console designs are changing dramatically. It appears that the lack of instructor function data has led to the proliferation of displays and controls. This may well be detrimental to the effectiveness of training.

Finally, the role of the Fleet Squadron IP was reviewed. Major decisions regarding fleet use of simulators must be made before the role can be defined. At present, fleet squadron use of simulation is minimal. Effective use will depend on the IP and NFOI roles in training as well as trainer availability.

The major recommendations were:

a. Establish role of Instructor Pilot as developed in the study.

b. Develop a simulator utilization training program for Instructor Pilots and Simulator Operators.

c. Develop a course in instructional methods for Instructor Pilots.

d. Develop the specialized syllabi required for simulator training.

e. Develop detailed instructor console design objectives and criteria.

f. Expand the utilization of procedures trainers to free operational flight trainer and weapons systems for instrument and tactics training.

g. Establish policy on Fleet Squadron use of simulators, develop required syllabi, and train Instructor Pilots.

h. Establish Naval Flight Officer Instructor's role in simulator training and interactions with Instructor Pilot's role and finalize simulator utilization concept.

Elworth, C. (1981). Instructor/operator display evaluation methods (AFHRL-TR-79-41, AD-A097 208). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Abstract. The purpose of this study was to develop an objective, systematic technique for evaluating alternative formats for the displays to be used at the instructor/operator station (IOS) of a flight simulator. A benchmark performance monitoring task was designed which exercises many of the skills used by an instructor at a remote IOS. Measurement techniques were developed for assessing performance of the task. The techniques were demonstrated by using them to compare two popular display formats: digital readouts versus repeater instruments. Three of six variables were monitored with greater accuracy and comprehensiveness using repeater instruments than digital readouts. For the other three variables, there was no difference between display types. Significant effects were caused by both the type of maneuver being flown and the type of question being asked in administering the measurement method. We concluded that the benchmark task approach has considerable merit as a method of evaluating display formats. In follow-on studies, additional investigations should be conducted on the specifics of the measurement technique and the possible effects of memory on results.

Golovcsenko, I.V. (1974). Acoustic tablet data input from instructor consoles: An interim report on computer display interactive scenario development (NAVTRAEQUIPCEN-IH-239, AD-A001 276). Orlando, FL: Computer Laboratory, Naval Training Equipment Center.

Abstract. A method of data entry from a graphical tablet was developed. The method enables the insertion of geographical mission parameters directly from a map, a method which is much less time-consuming than use of either punched card or teletypewriter keyboard entry.

Golovcsenko, I.V. (1974). A computer light-pen input technique for data entry from instructor consoles (NAVTRAEQUIPCEN-TN-37, AD-779 074). Orlando, FL: Computer Laboratory, Naval Training Equipment Center.

Abstract. A computer-generated display program was developed to investigate light-pen data entry techniques to augment or replace standard alphanumeric keyboards at the instructor station. Written for the IDIIOM computer system, the program generates a typical display page from the 15E22 trainer, and, in conjunction with the light-pen, uses a simulated keyboard on the CRT screen for entering, removing and altering alphanumeric data.

Gray, T.H., Chun, E.K., Warner, H.D., & Eubanks, J.L. (1981). Advanced flight simulator: Utilization in A-10 conversion and air-to-surface attack training (AFHRL-TR-80-20, AD-A094 608). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Abstract. The purposes of this research were to develop transition and surface attack simulator training programs for novice A-10 pilots and to determine simulator features and capabilities required for effective training in the air-to-surface (A/S) mission. These goals were refined to four specific objectives: development of a transition and surface attack syllabus; generation of objective performance measurement algorithms; determination of design requirements for instructor stations; and assessment of the utility of advanced instructional features.

These objectives were accomplished using A-10 Instructor Pilots and four classes of "B" course students who had recently completed Undergraduate Pilot Training and Fighter Lead-In School. Each class received two blocks of instruction on the Advanced Simulator for Pilot Training (ASPT). The first block consisted of 4 to 8 hours of conversion training with primary emphasis on traffic pattern work. The second block of training was composed of 4 to 7 hours of A/S weapons delivery (i.e., dive bombing and strafe).

The key findings of the study were:

1. For the initial phases of weapons delivery training, the transfer of training from the ASPT to the A-10 is nearly 100 percent; therefore, in the early phases of A/S training, one simulator mission can effectively replace one aircraft mission, thus allowing actual flying time to be transferred to other phases of training.

2. Objective assessments of piloting and weapons delivery skills are highly useful in A-10 training.

3. Improvements are needed in the display and controls at the A-10 instructor station.

4. Many advanced instructional features are not fully utilized by the IPs, implying either that they may not be required for achieving effective weapons delivery training or that the IPs need more training on the use of these features to enhance student learning.

Hinton, W.M., Jr., & Komanski, W.M. (1982). Instructor/operator station design study (NAVTRAEQUIPCEN-N61339-80-D-0009-1). Orlando, FL: Code N-251, Naval Training Equipment Center.

Abstract. The goal of the study was to develop generic Instructor/Operator Station designs which would improve the instructor's ability to carry out his instructional responsibilities during simulation training. Current Instructor/Operator Station designs were assessed and their strengths and weaknesses evaluated. Design principles were developed to enhance the strengths and eliminate the weaknesses. Two alternative generic Instructor/Operator Station designs are presented. The designs are comparable in training capability. They differ in their methods of instructor control. Alternative 1 features almost exclusive use of CRT touch panels. Alternative 2 features a mixture of CRT touch panels and panel-mounted electronic touch pads. Advantages and disadvantages of each alternative are presented.

Lewis, J.L. (1979, October). Operator station design system: A computer aided design approach to work station layout. In C.K. Bensel (Ed.), Proceedings of the 23rd Annual Meeting of the Human Factors Society (pp. 55-58). Santa Monica, CA: Human Factors Society.

Abstract. The Operator Station Design System is resident in NASA's Johnson Space Center Spacecraft Design Division Design Performance Laboratory. It includes stand-alone mini-computer hardware and Panel Layout Automated Interactive Design and Crew Station Assessment of Reach software. The data base consists of the Shuttle Transportation System Orbiter Crew Compartment (in part), the Orbiter payload bay and remote manipulator (in part), and various anthropometric populations. The system is utilized to provide panel layouts, assess reach and vision, determine interference and fit problems early in the design phase, study design applications as a function of anthropometric and mission requirements, and to accomplish conceptual design to support advanced study efforts.

Osborne, S.R., Semple, C.A., & Obermayer, R.W. (1983). Three reviews of the Instructional Support System (ISS) concept (NAVTRAEQUIPCEN-81-C-0081-1, AD-A129 043). Orlando, FL: Code N-711, Naval Training Equipment Center.

Abstract. The Instructional Support System (ISS) examined in this report is aimed at (1) increasing the utilization of existing simulators, and (2) improving the quality of training. The ISS can be strapped onto existing flight simulators without hardware or software modification. It provides an interface which instructors and students can use instead of the existing displays and controls. The ISS development had three subgoals: (1) to relieve the instructor of ancillary instructional tasks (e.g., problem setup, note taking, mission communications), (2) to provide automatic ancillary instructional tasks (e.g., computer-generated briefings, automated checkrides, automated performance measurement), and (3) to provide a research tool to enable solution of unresolved design issues.

This report describes the resulting ISS and tests conducted at VF-124, Miramar NAS. An analysis of the ISS concept which emerged is presented from the viewpoints of instructional design, operational instruction, and performance measurement design.

Polzella, D.J. (1987). Aircrew training devices: Utility and utilization of advanced instructional features (Phase IV - Summary report) (AFHRL-TR-87-21, AD-). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Summary. Modern Aircrew Training Devices (ATDs) are equipped with sophisticated hardware and software capabilities, known as Advanced Instructional Features (AIFs), that permit a Simulator Instructor (SI) to prepare briefings, manage training, vary task difficulty/fidelity, monitor performance, and provide feedback for flight simulation training missions. The utility and utilization of the AIF capabilities of USAF ATDs was explored by means of a survey of 534 SIs from Air Training Command, Military Airlift Command, Strategic Air Command, and Tactical Air Command training sites. The primary purpose of the survey was to provide a database that could be used to help define the requirements for ATD procurements and help develop future ATD training programs. In general, the features that were rated highest in utility and utilization were those used for training management, variation of task difficulty/fidelity, and monitoring student performance. The level of AIF use was affected somewhat by hardware and/or software unreliability, implementation time, functional limitations, and design deficiencies. However, the presumed training value of an AIF was the most important determiner of its use. Recommendations are made concerning the AIF capabilities of future ATDs and the need for empirical research aimed at determining the principles of effective AIF use.

Polzella, D.J., & Hubbard, D.C. (1986). Aircrew training devices: Utility and utilization of advanced instructional features (Phase III - Electronic warfare trainers) (AFHRL-TR-85-49, AD-A167 922). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Summary. Aircrew training devices (ATDs) are often equipped with sophisticated hardware and software capabilities that permit a simulator instructor (SI) to control, monitor, record, and fabricate flight simulation training missions. These advanced instructional features (AIFs) reflect the ATD's primary role as a flight trainer. The training value of an ATD is a function of the degree to which it simulates a particular aircraft and the way in which it is used as an instructional device.

AIFs are costly to implement. In order to justify these costs, several questions must be answered: (a) How frequently are AIFs used? (b) How easy are they to use? (c) Are simulator instructors adequately trained to use AIFs? (d) Do AIFs have significant training value?

This report describes the third phase of a three-phase project designed to obtain answers to these questions by surveying simulator instructors from the Air Force Major Commands. An on-site survey was administered to 159 SIs assigned to replacement training units and continuation training units at principal Air Training Command (T-5), Strategic Air Command (T-4, B-52 Weapon System Trainer FB-111A), and Tactical Air Command (F-4G, A-10) ATD facilities. The survey requested background information along with five seven-point rating scales for evaluating each of 14 AIFs. Written comments concerning the 14 AIFs or the ATD were solicited.

Based on the utility and utilization ratings, the T-5 and T-4 trainers were the most favorably evaluated devices surveyed. They were followed, in order, by the F-4G simulator, B-52 WST, and A-10 simulator. Mission control features (e.g., freeze, reset, programmed and manual threat control) were generally rated high in utility and utilization, whereas briefing features (e.g., instructor tutorial, recorded briefing, demonstration) and feedback features (e.g., hard copy, record/playback, electronic warfare performance scoring) tended to receive lower ratings.

The level of AIF-use was affected somewhat by hardware and/or software unreliability, implementation time, functional limitations, and design deficiencies. The perceived training value of a feature was the most important determiner of its use.

Polzella, D.J. (1985). Aircrew training devices: Utility and utilization of advanced instructional features (Phase II - Air Training Command, Military Airlift Command, and Strategic Air Command) (AFHRL-TR-85-48, AD-A166 726). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Summary. Aircrew training devices (ATDs) are often equipped with sophisticated hardware and software capabilities that permit a simulator instructor (SI) to control, monitor, record, and fabricate flight simulation training missions. These advanced instructional features (AIFs) reflect the primary role of the ATD as a flight trainer. The training value of an ATD is a function of the degree to which it simulates a particular aircraft and the way in which it is used as an instructional device. AIFs are costly to implement. In order to justify these costs, the following questions must be answered: How frequently are AIFs used? How easy are they to use? Are SIs adequately trained to use AIFs? Do AIFs have significant training value?

This report describes the second phase of a three-phase project designed to obtain answers to these questions by surveying SIs from the Air Force Major Commands (MAJCOMS). An on-site survey was administered to 273 SIs assigned to replacement training units (RTUs) and continuation training units (CTUs) at principal Air Training Command (ATC) (T-37, T-38), Military Airlift Command (MAC) (C-5A, C-141, C-130, CH-3, HH-53), and Strategic Air Command (SAC) (FB-111A) ATD sites. The survey requested background information along with five seven-point rating scales for evaluating each of 16 AIFs. Written comments concerning the 16 AIFs or the ATD were solicited. The most striking difference between the Phase I (TAC survey) and Phase II results was in the overall magnitude of the ratings. In comparison to the TAC SIs, the ATC, MAC, and SAC SIs used AIFs more often, found them easier to use, received more training in their use, and considered AIFs to be more important for training. The results suggested that TAC's SI training program is less extensive and less structured than those of the other MAJCOMS.

Features such as freeze, reset, motion, environmental, and crash/kill override were consistently rated high in utility and utilization, whereas features such as automated malfunction insertion, demonstration, record/playback, and hard copy were generally rated lower. The level of AIF use was affected somewhat by hardware and/or software unreliability, implementation time,

functional limitations, and design deficiencies. The perceived training value of a feature was the most important determiner of its use.

Polzella, D.J. (1983). *Aircrew training devices: Utility and utilization of advanced instructional features (Phase I - Tactical Air Command)* (AFHRL-TR-83-22, AD-A135 052. Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Abstract. An Aircrew Training Device (ATD) is not merely a flight simulator. It is also equipped with sophisticated hardware and software capabilities, known as advanced instructional features (AIFs), that permit a flight crew instructor to control, monitor, and record flight simulation training sessions. A survey conducted at five of the principal Tactical Air Command ATD sites revealed that few instructors receive extensive training in AIF use and that most features are not used very often. Several factors appear to have contributed to the low rate of AIF use. These factors include hardware and/or software unreliability, time-consuming implementation, functional limitations, and design deficiencies. Although many AIFs were judged to have significant value in replacement and/or continuation training, some features need to be made more reliable and user-friendly before their training effectiveness can be ascertained. It was recommended that a more formalized intensive training program for ATD instructors be established. Such a program would teach instructors not only how to use AIFs but, more importantly, how to use them effectively.

Ricard, G.L., Crosby, T.N., & Lambert, E.Y. (Eds.) (1982). *Workshop on instructional features and instructor/operator station design for training systems* (NAVTRAEQUIPCEN-IH-341). Orlando, FL: Human Factors Laboratory (Code N-71), Naval Training Equipment Center.

Abstract. On 10 and 11 August 1982, the Naval Training Equipment Center hosted a Workshop on Instructional Feature and Instructor/Operator Station Design for Training Systems, and this report documents the papers presented at that workshop. These reports describe research and development projects, human engineering surveys, new designs developed for one trainer or another, and suggestions for new features as yet not well developed. Together they represent the current state of thinking about the functions training devices should provide for the personnel using them.

Sanders, C.D. (1981). *Task analytic techniques: Application to the design of a flight simulator instructor/operator console* (AFHRL-TP-81-38, AD-A108 724). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Abstract. Instructional Systems Development (ISD) has contributed to the efficiency and low cost of air flight training through the medium of the simulator. Task analysis is a component of ISD, and its application to the improvement of devices such as simulator instructor/operator consoles will continue to enhance the quality of flight training. Task analytic techniques are inextricably interwoven into the design of an instructor/operator console. The application involves the process, persons, and a machine within the context of a flight simulator. The tasks of the instructor and student are primary in the design process. The efficiency and economy of the task analytic process has implications for its use in the future developments of automated flight training.

Schwartz, N.F. (1977). Display and speech devices for simulator instructor/operator station applications (AFHRL-TR-77-50, AD-A049 247). Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

Abstract. The Air Force Human Resources Laboratory (AFHRL) has the responsibility for research and development of advanced simulation techniques, including more efficient and more effective Instructor Operator Stations (IOS) which would possibly use newly developed display devices and techniques and speech response/recognition devices.

This review was undertaken to become better acquainted with the state of the art of hardware devices which could be used for the IOSs of advanced aircraft training simulators and to provide some guidance in these devices to designers, specifiers and users of IOSs. Attention focused mainly on display devices and speech response/recognition devices.

A survey of technical literature concerning display devices, and speech synthesis and speech recognition devices was accomplished and contacts were established with a number of manufacturers and developers of these devices to determine the latest developments and potential applications. Also, literature was searched for R&D related to the application of such devices.

Some of the merits and shortcomings of a number of display devices (i.e., cathode ray tubes (CRT) and alternative but similar devices) are discussed and descriptions of their operation are included. Speech interaction with computers is also discussed in a similar manner.

It is concluded that new display devices will not significantly impact the general design or utilization of the IOS. Advancement of speech recognition could have a significant impact, but development beyond present capabilities does not appear imminent.

Semple, C.A., Cotton, J.C., & Sullivan, D.J. (1981). Aircrew training devices: Instructional support features (AFHRL-TR-80-58, AD-A096 234). Wright-Patterson AFB, OH: Logistics and Technical Training Division, Air Force Human Resources Laboratory.

Abstract. This report presents relationships between aircrew training device (ATD) instructional support features and training requirements. Instructional support features include ATD hardware and software capabilities that permit instructors to manipulate, supplement or otherwise control student learning experiences. The instructional features addressed are (a) freeze; (b) automated demonstrations; (c) record and replay; (d) automated cuing and coaching; (e) manual and programmable sets of initializing conditions; (f) manual and programmable malfunction control; (g) ATD-mounted audio visual media; (h) automated performance measurement; (i) automated performance alerts; (j) annunciator and repeater instruments; (k) closed circuit television; (l) automated adaptive training; (m) programmed mission scenarios; (n) automated controllers; (o) graphic and text readouts of controller information; (p) computer-controlled threats; (q) computer-managed instruction; (r) recorded briefings; (s) debriefing aids; and (t) hardcopy printouts. Each feature is discussed, as appropriate, in terms of (a) its operation, (b) related features, (c) instructional values, (d) observed applications, (e) utility (use-related) information, (f) related research, and (g) design considerations.

Sher, L.D. (1981). *Flight simulator: Us[illegible]pacegraph display in an instructor/operator station* (AFHRL-[illegible]-60, AD-A101 951). Williams AFB, AZ: Operations Training Division, Air Force Human Resources Laboratory.

Abstract. SpaceGraph is described as a new computer-driven display technology capable of showing space-filling images, i.e., images that are truly three-dimensional. This report details the findings on how this new technology can be used in, and in conjunction with, the Instructor/ Operator Station (IOS) of a flight simulator.

In current practice, the location, altitude and flight attitude of a simulated aircraft are graphically shown to the instructor/operator on flat screens. This dimensionally mismatched form of data presentation creates a greater workload on the instructor/operator, who must integrate several flat presentations into a mental construct of performance in three-dimensional space. Such space-filling data should be shown with a space-filling display, now that one exists.

Unexpectedly, student pilots were also able to use the display directly. As a training aid intermediate between "flying" one's hands in the classroom and "flying" the big simulators, it would appear to be a new kind of low-cost, part-task training vehicle. It offers the realism of computer-produced flight dynamics but with a view of the aircraft rather than out of the aircraft.

Smode, A.F. (1974). Recent developments in instructor station design and utilization for flight simulators. *Human Factors*, *16* (1), 1-18.

Abstract. The instructional capability of the training simulator has improved in tempo with simulation technology. The business of shaping student behaviors has achieved a leap forward in efficiency due to digital computation and the computer display terminal. This paper discusses the impact of computer assistance on the capability for structuring and controlling synthetic flight training, and examines the instructional potential of the "new breed" of flight simulators presently on-line or in the developmental stage. A number of recent innovations in instructor station design are described. These developing, student- centered instructional techniques for promoting training effectiveness place the simulator quite realistically in contention as a major flight training medium of the future.

Smode, A.F. (1972). *Training device design: Human factors requirements in the technical approach* (NAVTRAEQUIPCEN-71-C-0013-1, AD-754 744). Orlando, FL: Naval Training Equipment Center.

Abstract. This report presents guidelines for achieving the human factors inputs to the Technical Approach in the training device design process. A method is provided which facilitates the correlation of instructional requirements with engineering design solutions. Techniques and procedures are recommended for organizing the information requirements which must be accounted for in the engineering design in order to maximize the instructional potential of a device.

Three major sections are provided. The first of these presents techniques and procedures for deriving the information requirements relative to achieving simulation fidelity in trainee station design.

The second section presents procedures for deriving the information requirements involved in setting up, controlling, monitoring and evaluating performance at the instruction station. Fourteen chapters describe the information requirements pertinent to the structure and control of training during off-line, pre-mission, enroute training and post-exercise operations.

The last section discusses the human factors test and evaluation requirements in the training device acceptance process. Procedures are outlined for verifying the suitability of a training device as an instructional system. The test, evaluation and demonstration requirements throughout device fabrication are organized to assist the human factors specialist in determining that the device performs as advertised.

Smode, A.F. (1971). *Human factors inputs to the training device design process* (NAVTRADEVCEN-69-C-0298-1, AD-734 644). Orlando, FL: Human Factors Laboratory, Naval Training Device Center.

Abstract. This report presents guidelines for achieving human factors inputs to the design of synthetic training systems. It provides a method for design and organizes training concepts and data supportive to the human factors specialist in deriving the functional specifications for the design of any complex training device.

Three major sections are provided. The first of these presents an organized method for achieving human factors inputs to training system design.

Another section presents concepts and data applicable to the design of training devices. Seven content chapters are subsumed under this section. These are: (1) visual simulation, (2) platform motion simulation, (3) vehicle control requirements, (4) information processing requirements, (5) measurement system design, (6) adaptive training strategies, and (7) deliberate departure from realism in design. For each chapter, concepts and data which provide human factors design support are articulated based on a review of the pertinent literature. Where design evidence is meager, the data gaps are identified. Research issues of high priority for human factors design are recommended.

The final section provides a demonstration of the human factors design process for a complex training system. A reconstruction of the human factors specifications for Device 14A2, ASROC/ASW Early Attack Warning System Trainer, is presented. The required human factors inputs are systematically explored based on the method mentioned above. Viewing an "on-line" training device in retrospect provides the opportunity to examine the credibility of the method proposed in this report, particularly in relation to the design achieved. It also enables the reconstruction of the key human factors decision points including an examination of the possible design alternatives in terms of what effects these could have had on the instructional capability of the device.

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